Healthy Rivers
PLAN FOR CHANGE
Wai Ora
HE RAUTAKI WHAKAPAIPAI

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Evaluation of scenarios for water-quality improvement in the Waikato and Waipa River catchments

Assessment of second set of scenarios
24 September 2015

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1. Introduction

The Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai (HRWO) project will establish targets and limits for nutrients (nitrogen and phosphorus), sediment, and *E. coli* in water bodies across the Waikato and Waipa catchments. As part of the process of establishing targets and limits, the Collaborative Stakeholder Group (CSG) asked for a technical assessment of four initial scenarios. These initial scenarios were associated with a diverse set of goals for water-quality improvement, and were purposely developed by the CSG to help them to explore a wide range of 'possible futures' and timeframes to achieve them. Based on their analysis of a modelling assessment provided for this initial set of scenarios, the CSG have recently provided an alternative set of scenarios to explore.

The alternative set of scenarios has a number of different parts, but all relate towards examining movements towards the most-aspirational of the initial water-quality scenarios set by the CSG (Scenario 1). Scenario 1 is characterised by substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This involves an improvement in water quality everywhere in the catchment, even if it is already meeting the minimum acceptable state. The water-quality attribute set that is the focus of Scenario 1 includes limits defined across a broad range of attributes: chlorophyll *a* (median and maximum), Total Nitrogen, Total Phosphorus, nitrate (median and 95th percentile), *E. coli* (median and 95th percentile), and water clarity.

The key goal of the next stage of assessment is to evaluate what extent of change is required to achieve 10, 25, 50, 75, and 100% steps from the current state towards Scenario 1. A step of *x*% towards Scenario 1 means that all limits defined across the catchment move x% from their current state to that state defined under Scenario 1. For example, if the current state median-nitrate level for a site is 2 g m^{-3} and the Scenario 1 goal for this site is a median-nitrate level of 1 g m^{-3}, then a 10% movement would mean that the simulated limit is 1.9 g m^{-3}. Likewise, a 25% movement would mean that the simulated limit is 1.75 g m^{-3}. Thus, as the percentage of the step increases, so the run more closely resembles that in Scenario 1. Indeed, a 100% movement would mean that a limit of 1 g m^{-3} holds; thus, this is consistent with Scenario 1 holding in its entirety. These steps are evaluated across a range of cases, which differ according to the degree that land-use change is constrained and whether or not reductions in Total-Nitrogen concentration are required alongside constraints levied against all other contaminants.

The purpose of this report is to describe outputs from a predictive-modelling approach that aimed to identify the implications of altering land and point-source management to achieve the water-quality limits proposed for each step towards Scenario 1, across each of the alternative cases. The modelling approach used chiefly sought to predict the economic implications of these scenarios at the farm, catchment, regional, and national scales.

The model utilised in this report represents a key contribution of the Technical Leaders Group (TLG) to the CSG’s deliberations, given that it integrates diverse information generated from a broad array of technical work streams that the TLG has initiated and managed. Economic modelling is an important input to the CSG deliberation process, to describe ‘plausible futures’ and so support deliberations leading to policy-development decisions.

2. Methods

This section describes the economic-modelling approach used in this analysis. The first part describes the structure of the catchment-level model, while the second part outlines specific details regarding its application to the Waikato and Waipa River catchments. The third part of this section outlines the input-output model that is linked to the catchment-level framework. This input-output model determines the regional- and national-level economic implications of the effects of the alternative model runs conducted at the catchment-level. The fourth part describes the scenarios that these models are utilised to explore.

2.1 Structure of the catchment-level model

The catchment-level model is an optimisation model–that is, it determines the least-cost combination of mitigation measures (land management, land-use changes, and point-source treatments) required to meet the water-quality attribute limits set for each scenario. An iterative process is used to identify how different mitigations could be implemented to minimise the cost associated with achieving a given limit (Doole, 2015). The term “optimisation” conveys how the iterative process seeks to *minimise* the cost of a change, and contrasts a simulation approach in which a model user evaluates different scenarios involving pre-defined management activities across the landscape of interest. This particular optimisation model uses a method known as mathematical programming (Bazaraa et al., 2006).

An economic model is essentially a collection of equations and decision variables that seek to describe some part of a complex reality. A decision variable in an optimisation model is a term that is identified by a model during its solution, while equations are pre-defined and outline the logic that the decision variables must obey. A key type of equation utilised in the form of mathematical modelling that is utilised in this study (mathematical programming) is a constraint. These constraints can define key relationships (i.e. a relational constraint), or can be used to restrict the level of certain decision variables (i.e. a limit). A key relationship used in the economic model applied here are limit constraints defining the bounds for given contaminants at different sites within the catchment. To describe a complex reality within a mathematical model, it is necessary to formulate various assumptions that permit practitioners to develop an understanding of the relationships between certain key levers. Without these assumptions, it is difficult to formulate such an understanding. The key assumptions underlying the economic model utilised here have now been peer-reviewed by leading national and international experts.

The model structure is loosely based on that of the Land Allocation and Management (LAM) catchment framework (Doole, 2012, 2015). The flexibility of this model is demonstrated in its broad utilisation across a number of nonpoint-pollution contexts, both nationally (Doole, 2013; Howard et al., 2013; Holland and Doole, 2014) and internationally (Beverly et al., 2013; Doole et al., 2013). Key benefits associated with the application of the LAM framework are (Doole, 2015):

1. Its flexible structure allows it to be adapted to diverse circumstances.
2. The complexity of the model can be altered, depending on the quality and quantity of resources available.
3. The model can be efficiently coded in popular nonlinear-optimisation software, such as the General Algebraic Modelling System (GAMS) (Brooke et al., 2014), that allows matrix generation.
4. The structure of the model allows the use of a broad range of calibration techniques.
5. Models of substantial size can be constructed (Doole, 2010).

The flexibility of the modelling structure has been particularly critical to the development of the model utilised in this study, as it contains broadly-diverse relationships between land use, land management, contaminant loss, mitigation activity, pollutant attenuation, groundwater flows of nitrogen, and links between loads and concentrations.

Key mitigation costs included in the model are those associated with stream fencing, upgrading of effluent management on dairy farms, farm plans for erosion control on dairy and dry-stock farms, enhanced point-source treatment, transition costs associated with the replacement of one type of farming activity with another, and edge-of-field mitigations.[1] The efficacy of these mitigations and their costs has been gathered from a variety of literature sources, individual experts, and expert-panel workshops convened by the TLG. A separate mitigations report is currently being finalised after extensive peer review.

Alongside these costs associated with mitigation, costs may also accrue through a decrease in farm profit associated with the de-intensification of a current land use or transition into a new land use. Changes to farm profit associated with different mitigation activities are computed using FARMAX for pastoral enterprises, farm budgeting for horticultural enterprises, and the Forest Investment Finder (FIF) for plantation forest. Inputs have been developed through interaction with technical experts within these sectors and industry organisations. A detailed discussion of these data is described in the mitigations report referred to above.

The LAM framework is characterised by delineation of the catchment into a number of partitions. The HRWO model involves:

1. Partitioning of the catchment into the four Freshwater Management Units (FMUs) agreed to by the CSG. These are Upper Waikato (Taupo Gates to Karapiro), Middle Waikato (Karapiro to Ngaruawahia), Lower Waikato (Ngaruawahia to Port Waikato), and Waipa. The area contained within the Shallow-Lakes FMU is included in the model, but is not studied independent of the others in this report.
2. Further partitioning of the area within each FMU into sub-catchments, many associated with their own monitoring site for a set of water-quality attributes.

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[1] Examples of edge-of-field mitigations include bunds, sediment traps, and wetlands.

3. Additional division of these 74 sub-catchments within the catchment into zones that represent farming systems of a consistent type (in terms of contaminant loss).

The information utilised in step (3) was based initially on that generated by the Economic Impact Joint Venture (EIJV) program of work that preceded the HRWO process. Nonetheless, the information generated by the EIJV was mainly focused on the dynamics of nitrogen leaching. Thus, a key focus of subsequent work within the HRWO process has been the extension of the EIJV economic model to consider the loss and mitigation of phosphorus, sediment, and *E. coli* loadings to water.

A key addition to the EIJV economic model has also been the integration of diverse hydrological/water quality models that relate contaminant losses within and across sub-catchments to pollutant concentrations at the various monitoring sites represented within the catchment. These models concern *E. coli* (Semadeni-Davies et al., 2015a), sediment (Yalden and Elliott, 2015), nitrogen (Semadeni-Davies et al., 2015b), and phosphorus (Semadeni-Davies et al., 2015b). The integration of these models into the economic model allows the depiction of an explicit relationship between land management, point-source management, and concentrations of chlorophyll *a*, Total Nitrogen, Total Phosphorus, nitrate, *E. coli*, and black disc measurements at different sites across the catchment.

A key feature of these hydrological/water quality models are estimated fate-transport matrices, which specify the flow and attenuation of contaminants between linked sites in the monitoring network. Various limits are evaluated in the scenarios through specifying the attribute concentrations that meet the scenario's desired band for median concentrations of chlorophyll-a, maximum concentrations of chlorophyll-a, Total Nitrogen concentration, Total Phosphorus concentration, median nitrate concentration, 95th percentile nitrate concentration, median *E. coli* concentration, 95th percentile *E. coli* concentration, and water clarity. The economic model then identifies the given set of mitigations, out of all of those sets that could be employed, required across the landscape to achieve these limits at least cost. Other objectives could be utilised to select the most-suitable management plan. However, using cost as a measure of the suitability of alternative management plans is commonplace (Daigneault et al., 2012; Doole, 2013) because of the central importance of societal cost when designing environmental policy (Hanley et al., 2007).

In keeping with standard practice (e.g. Hanley et al., 2007; Doole, 2010; Daigneault et al., 2012), the time path of adaptation is not included in the model, because:

1. The scarcity of data related to many relationships represented in the model is compounded when variation over time in key drivers of management behaviour (e.g. output price, input price, productivity, climate, innovation) is high and difficult to predict. An example is attempting to predict milk-price variation over the next few years, and how this influences mitigation costs for dairy farmers and related industries.
2. Dynamic models are difficult to develop and utilise because of their size and the demands they place on information gathering (Doole and Pannell, 2008).
3. Output from intertemporal models is heavily biased by the starting and endpoint conditions defined during model formulation (Klein-Haneveld and Stegeman, 2005).

Overall, these issues provide a strong justification for the employment of a steady-state modelling framework. In terms of the model runs outlined below, the CSG might choose to consider the steps towards Scenario 1 as movements along a timeline of change.

2.2 Application of the catchment-level model

The modelling application involves an analysis of 74 sub-catchments, which are further disaggregated into representative farms for dairy, dairy support, drystock, and horticulture sectors according to the characteristics of land and land management within these zones. Furthermore, 24 point sources are represented across the catchment, consisting of both industrial and municipal sources. Data on point source loadings was obtained from Vant (2014) and on costs of point source abatement from OPUS International Consultants (2013), modified following further consultation with the dischargers (Blair Keenan Waikato Regional Council). The economic and environmental characteristics of plantation forest across the entire catchment are also estimated utilising information from Scion, expert opinion, and past studies.

The number of representative farms contained within a catchment-level economic model can, in principle, range from a single farm representing the entire catchment to representing each specific farm individually (Doole and Pannell, 2012). Realistically, a shortage of data of a sufficient quality and quantity restricts our capacity to represent individual farms with any precision (Doole, 2012); this is particularly problematic in New Zealand due to confidentiality restrictions. Aggregation into representative farms is a pragmatic ‘half-way house’ that is likely to introduce some prediction error, in terms of estimating both contaminant losses and mitigation costs. However, larger errors can often accompany representations of individual farms, given a paucity of data available at that scale. Moreover, it removes the ability to study the movement of contaminants across the catchment, as the subsequent model is sufficiently large and unwieldy that the complexities involved with attenuation relationships and flow paths cannot be considered. Additional justifications are that the model becomes more difficult to interpret (Holland and Doole, 2014), while there is also the fact that mean trends remain the most-relevant anyway, since trends for farms on one side of the average offset the impact of those on the other (Doole, 2012). Issues of spatial aggregation and scale are common in natural-resource modelling approaches of this kind, and it is important to remain cognisant of these limitations when interpreting the model outputs.

The model uses historical land-use patterns to constrain land-use changes to realistic levels. This approach was deemed appropriate in this application because it is straightforward to code, much easier to formulate and less prone to error than forcing calibration through the use of arbitrary calibration functions (Doole and Marsh, 2014), draws on regionally-specific data, and is the only land-use calibration method that has a rich theoretical justification (Onal and McCarl, 1991; Chen and Onal, 2012). Historic land-use patterns observed for a distinct region (i.e. sub-catchment) provide specific insight into the type of land-use change that can occur there. Indeed, these patterns provide spatial information regarding the implicit aggregate and biophysical factors that guide land-use change within this area. Using this historical information within the catchment model applied here allows the specification of a well-behaved aggregate model, despite lacking data for individual farms (Onal and McCarl, 1991; Chen and Onal, 2012). To use this approach, historic land use for each sub-catchment across 1972–2012 was drawn from the work of Hudson et al. (2015). The optimisation procedure then identified the best weighted average of these historic land-use sets that attained the environmental limits set out by each scenario at least cost.

Sometimes, it is possible that environmental limits cannot be met. For example, model output presented below shows that this is particularly relevant to sites where 95th percentile *E. coli* loadings are highest in the catchment. Normally, such violations will cause infeasibility of a mathematical-programming model, as there is no way that all limits can be met subject to the other relationships within the model remaining satisfied. To prevent such disruption to the solution of the model, the limits defined within each scenario are formulated as soft constraints through the use of elastic programming (Gill et al., 2005).

Some mitigation practices involve the establishment of enduring assets; for example, the development of stand-off pads or riparian fences. The inclusion of their establishment costs as a lump sum would bias cost estimation. Therefore, according to standard practice (e.g. Howard et al., 2013), capital costs are converted to annual equivalent payments at an interest rate of 8% over a payback period of 25 years. Maintenance costs for these assets have also been considered. Forest profits have been annualised and it is important to recognise that, in reality, the returns associated with this activity will only be borne after harvest when trees are 28 years of age.

2.3 Application of the regional-level model

Input-output (IO) models are the most widely-applied method for estimating the regional impacts of environmental policy, both in New Zealand and overseas. Moreover, they are one of the most popular economic methods applied globally (Miller and Blair, 2009), based on their clarity and descriptive capacity. These models study the flow of products, inputs, and sales between households and industries. Their primary advantage is that they describe the complex interdependency between different sectors within an economy, allowing the consideration of numerous flow-on relationships arising from a change in current economic activity. Accordingly, input-output models provide a means to estimate the regional impacts of a given policy mechanism, based on the idea that an initial decrease in net revenue entering into a regional economy—for example, in response to a change in milk production arising from reduced dairy-production intensity—will lead to a decline in subsequent spending in other industries within this economy, but the effect of these diminished contributions will dissipate over time due to the leakage of funds from the local economy (e.g. through expenditure outside of the region or through saving) (Mills, 1993). Such models have many benefits; namely, their ability to capture interrelationships between different sectors, low cost, and apparent simplicity, which helps to promote the clarity of their output (Bess and Ambargis, 2013). Moreover, the equilibrium structure of input-output models is consistent with the steady-state approach employed in the catchment-level model discussed above.

At the core of any IO analysis is a set of data that measures, for a given year, the flows of money or goods among various sectors or industrial groups within an economy. These flows are recorded in a matrix or ‘IO table’ by arrays that summarise the purchases made by each industry (its inputs) and the sales of each industry (its outputs) from and to all other industries. By using the information contained within such a matrix, IO practitioners calculate mathematical relationships for the economy in question. These relationships describe the interactions between industries—specifically, the way in which each industry’s production requirements depend on the supply of goods and services from other industries. With this information it is possible to calculate, given a perturbation to the current state of a selected industry, all of the necessary changes in production that are likely to occur throughout supporting industries within the wider economy. For example, if one of the changes anticipated for one FMU were to be a loss in the amount of dairy farming, the IO model would calculate all of the losses in output that would also occur in industries supporting dairy farming (e.g. fertiliser production, fencing contractors, farm-machinery suppliers), as well as the industries that, in turn, support these industries.

As with all modelling approaches, IO analysis relies on certain assumptions for its operation. Among the most important is the assumption that the input structures of industries (i.e. the mix of commodities or industry outputs used in producing output for a specific industry) are fixed. In the real world, however, these ‘technical coefficients’ will change over time as a result of new technologies, relative price shifts causing substitutions, and the introduction of new industries. For this reason, IO analysis is generally regarded as most suitable for short-run analysis, where economic systems are unlikely to change greatly from the initial snapshot of data used to generate the base IO tables. This further justifies the selection of this method for the regional-level economic analysis, given that the catchment-level model presented above also represents a snapshot of reality that is based heavily on current prices, technologies, management practices, and knowledge of biophysical relationships. This also justifies the main focus on constrained land-use changes (Section 2.2), given that economic analysis is best equipped for studying marginal changes.

The study of economy-wide economic impacts in this study commenced with identifying six key categories of likely economic effects associated with the proposed options for water-quality improvement:

Changes to farming systems: backward linkage supply chain impacts. Attribute limits can encourage changes in land-management practices for farms within each FMU. Examples might include removing summer crops and replacing these with supplements and lowering fertiliser use. These measures result in changes to the purchasing patterns of farms, creating flow-on impacts through economic supply-chain linkages.

Changes to farming systems: forward linkage supply chain impacts. The changes in farming practices will also result in reductions to the overall output of farms. With less output (e.g. milk, wool, meat) produced per hectare, the supply to downstream processors (dairy manufacturers, meat processors, textile manufacturers, etc.) will be reduced, ultimately leading to a reduction in sales by these industries.

Conversion between land uses: backward supply chain impacts. In addition to changes in land management, the proposed scenarios will also likely result in changes in land use across the FMUs. This will create additional impacts for industries that would otherwise be involved in supplying goods and services to the existing farms. Businesses that are responsible for providing direct inputs to the forestry sector (e.g. pruning contractors, accountants etc.) will be positively impacted by the conversion of land from dairy farming to forestry. Businesses involved indirectly in forestry supply chains (e.g. firms selling supplies to contractors) will also be positively impacted.

Conversion between land uses: forward linkage supply chain impacts. Similar to the forward-linkage effects resulting from changes in farming systems, the conversion of land from one use to another will result in changes to the supply of key products to downstream processors (for example, more timber to wood processors, but less raw milk to dairy-product manufacturing, if dairy land is replaced by forest production).

Changes in incomes for land owners. For each of the scenarios evaluated, there will be changes in income for landowners in the form of wages/salaries and profits. This will cause changes in the expenditure patterns of these land owners; hence, impacting the rest of the economy.

Outlays and revenues associated with land conversion. The conversion of land into different uses is associated with a set of discrete capital investments and other economic transfers. For land owners, these can be both outlays (e.g. construction of woolsheds, planting costs) and revenues (e.g. sale of Fonterra shares, sale of dairy herds). The income and expenditure patterns of land owners will have flow-on implications through the district, regional, and national economies.

Changes for wood and paper processing. Baseline FMU wood- and paper-processing input mixes were replaced with superior data provided directly by Scion. This ensured that the latest available information on processing methods, unique to each FMU, was appropriately incorporated.

All employment results generated by the regional-level model are measured by using Modified Employee Counts (MECs). Statistics New Zealand typically reports employment data according to the Employee Count (EC) measure. ECs are a head count of all salary and wage earners for a reference period. This includes most employees, but does not capture all working proprietors—individuals who pay themselves a salary or wage. The modified employment count or MEC measure is based on ECs, but includes an adjustment to incorporate an estimate of the number of working proprietors.

2.4 Model runs

The key goal of this assessment is to evaluate what extent of change is required to achieve 10, 25, 50, 75, and 100% steps from the current state towards Scenario 1. A step of *x*% towards Scenario 1 means that all limits defined across the catchment move x% from their current state to that state defined under Scenario 1. For example, if the current state median-nitrate level for a site is 2 g m^{-3} and the Scenario 1 goal for this site is a median-nitrate level of 1 g m^{-3}, then a 10% movement would mean that the new limit is 1.9 g m^{-3}. In comparison, a 100% movement would mean that a limit of 1 g m^{-3} holds; thus, this is consistent with

Scenario 1 holding in its entirety. The requirements of Scenario 1 are outlined in further detail in Table 1.

Table 1. The components of Scenario 1 that was proposed by the Collaborative Stakeholder Group during the CSG12 workshop, and subsequently accepted by the HRWO sub-committee.

Scenario description	**Attributes**			
	E. coli	**Clarity**	**Algae (Chlorophyll *a*)**	**Nutrients**
Substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This means: Swimmable in all seasons for microbes and clarity. Water quality supports ecological health. Some improvement in all parameters. [Represents CSG suggestion of *E. coli* to B, TP to minimum B, all others up one band – 'Restore']	Upper Waikato: Main stem remains A. Tributaries min B at 95% percentile (95%ile) Middle Waikato: Main stem A at Narrows at 95%ile; Horotiu and tributaries B Lower Waikato and Waipa: Main stem and tributaries B at 95%ile	Upper Waikato: Main stem A to Waipapa, tributaries go up 1 band Middle Waikato: Main stem B, tributaries go up 1 band Waipa: Upper stem B, lower stem C, tributaries go up 1 band Lower Waikato: C in main stem and tributaries	Upper Waikato: A sites improve. B sites to A, C sites to B. Middle Waikato: B for median, A for max. Lower Waikato: B for median and max; Huntly moves to B for med and A for max.	Total Phosphorus: Maintain where already A, raise to B for rest of river. Total Nitrogen: Improve where already A, all sites to Waipapa to A, rest of river to B. Ammonia and nitrate: Improve where already A, other sites go up 1 band.

These 10, 25, 50, 75, and 100% steps from the current state towards Scenario 1 are evaluated under three different cases:

1. All contaminants are bound according to the limits defined in that model run, and land-use change is constrained to lie within the range observed over the last forty years in each sub-catchment.
2. All contaminants are bound according to the limits defined in that model run. Current land-use management is fixed for the 10% and 25% steps, while unconstrained land use is defined for the 50%, 75%, and 100% steps. Unconstrained land use means that observed changes do not have to comply with historical land-use patterns.
3. All contaminants except Total Nitrogen are bound according to the limits defined in that model run, and land-use change is constrained to lie within the range observed over the last forty years in each sub-catchment.

Output for Case 1 is presented in Figures 1–4, Tables 2–6, and Tables 13–30. Output for Case 2 is presented in Tables 7–12. Data for Case 3 is presented in Figure 5.

The third case is the same as the first case, except Total Nitrogen is only required to be at or below its current level. The motivation for this case is that prior economic analysis conducted in the Upper Waikato (Doole, 2013) highlighted that mitigation activity targeted at addressing algal growth through limiting nitrogen delivery to the main stem of the Waikato River was expensive. Consequently, the third case provides for the situation whereby a focus on phosphorus mitigation may be sufficient to achieve goals outlined for chlorophyll-a, while also avoiding the high cost associated with reducing nitrogen loadings outlined in earlier studies.

Some model output differ from that identified in the equivalent run performed within the first assessment of scenarios, completed on 24 August 2015. There are various reasons for this. First, the initial set of scenarios defined by the CSG explicitly outlined that the nitrogen load to come within the catchment was to be considered in Scenario 4, but no guidance was given with regards to its inclusion in Scenarios 1–3. Subsequent consultation with the CSG has identified that the nitrogen load to come should from now on be considered in the other scenarios, as well. Second, the clarity model of Yalden and Elliott (2015) has been updated in response to peer review that was received following the application of the clarity model in the first assessment completed on 24 August 2015. Last, the application of the unconstrained land-use model has been reviewed, with some updating of the way that these runs are performed. Despite these improvements, the constrained land-use change model is still believed to be the most-appropriate instrument for prediction. A primary reason is that the biophysical and economic reality described in the model is likely to change significantly across the time frame that those vast changes in land use identified in the unconstrained land-use runs are observed.

3. Results and Discussion

3.1 Catchment-level output for Case 1, involving limits on TN and constrained land-use change

Figure 1 outlines the effect of each step on key elements of catchment profit, when land use is constrained to lie within those patterns observed in each sub-catchment over the last 40 years. It can be appreciated that the costs associated with 10% and 25% movements towards Scenario 1 are low to moderate (Figure 1), indeed, they are 3% and 7% of total profit, respectively (Table 2). This highlights that the diminishing returns to abatement activity are low at this stage, but are increasing as the attribute limits become more binding. Nevertheless, these catchment-level costs become significant as the steps move to 50% and above, demonstrating how strongly diminishing returns to mitigation are expressing themselves when water-quality improvement at this level is required (Figure 1).

Figure 1. Catchment-level cost for partial movement towards Scenario 1 with constrained land-use change. A 0% movement represents the current state. 10, 25, 50, and 75% steps towards Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state. A 100% step represents Scenario 1 in its entirety.

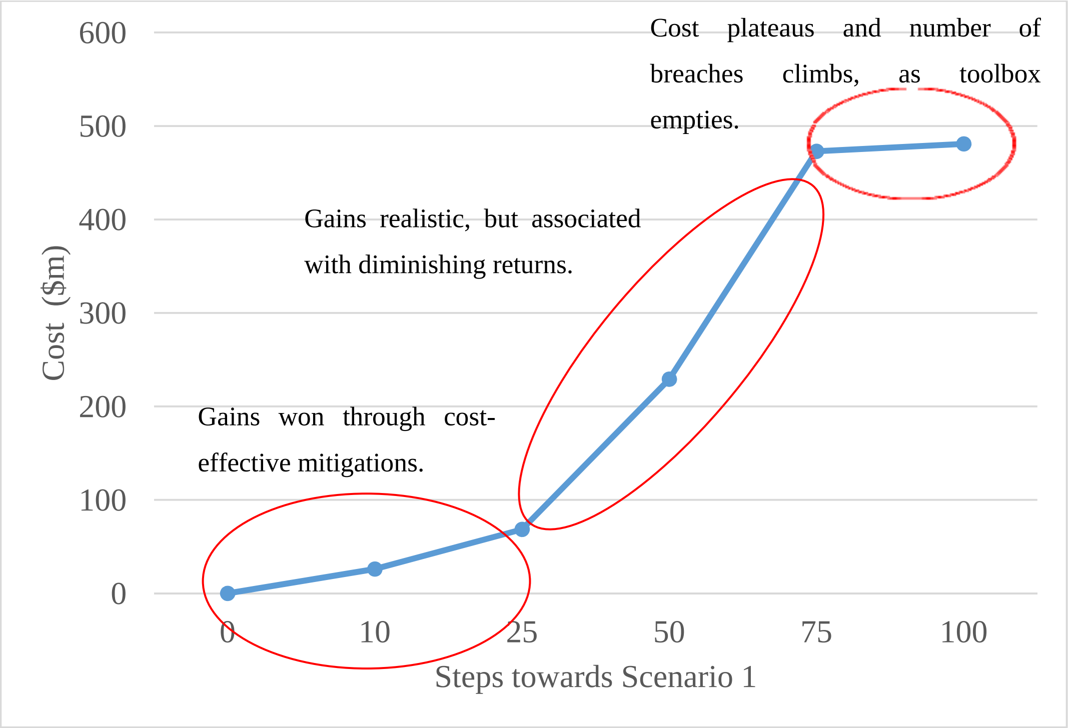
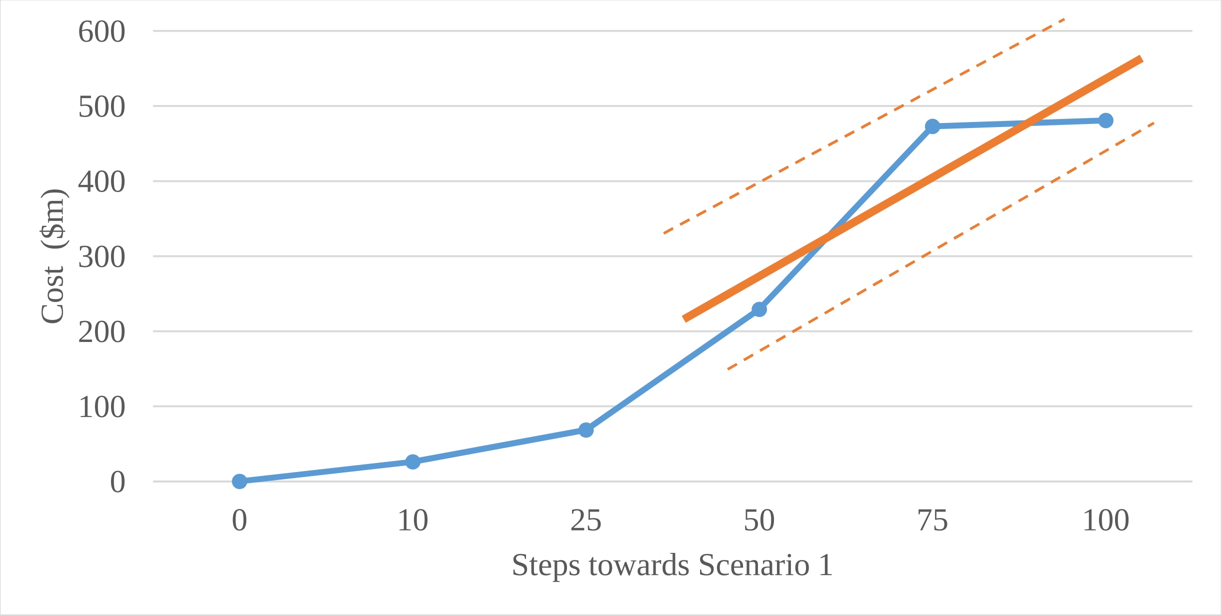


Figure 1 shows that the cost flattens off as the steps move to 75% and above. These solutions are qualitatively similar in that they represent a high cost associated with a high rate of mitigation. This is because further mitigation may be possible in some locations in the catchment, but it will not help attain further water-quality improvement. This highlights the limited efficacy of some mitigations; for example, the limited tools available for reducing *E. coli* incidence. Nevertheless, it stresses the importance of considering spatial processes in a model of this kind. One point particularly stresses the inability of further mitigation to further augment water quality. As water-quality limits become more stringent (i.e. through movement from a 75% to a 100% step), the number of breaches increases rather than cost increasing (see below). Of course, these insights are based on the assumption that land use is constrained, and further mitigation may be possible with unconstrained land-use change.

Figure 2. Catchment-level cost for partial movement towards Scenario 1 with constrained land-use change. (See label for Figure 1, for more information.)



Additional mitigation strategies may become available over time because of innovation and adaptation (Verspagen, 2009), though the cost and efficacy of these practices is not able to be predicted and is not included in the model. Figure 2 repeats Figure 1, but with the addition of orange lines. The thick orange line in Figure 2 shows the upward trend of cost associated with the model runs of 50, 75, and 100% steps, but with unconstrained land use change (Section 3.2). The gap between the upper hashed orange line and the thick orange line identifies the broad benefits associated with the ability of land-use change to reduce abatement cost across time through moving away from its current state. In comparison, the gap between the thick orange line and lower hashed orange line in Figure 2 is indicative of the potential gains associated with technical innovation.

Table 2 outlines the different components of catchment-level profit associated with the data shown in Figure 1. Movements associated with 10% and 25% steps impose a high cost on the dairy sector, with losses of 7% and 10% of baseline profit, respectively. Meanwhile, the drystock sector also loses profit of around 4% with the 25% step. The pastoral and horticultural industries bear a significant cost under the 75% step and the Scenario 1 simulation (Table 2). In contrast, the forestry sector experiences small gains in these instances. Point-source and edge-of-field mitigations grow in importance as limits become more binding. Practices to improve effluent management are not required until the 75% step, given the limited impact of these practices on the range of contaminants considered. Likewise, soil-conservation plans are first adopted at the 50% step and above, given that attribute limits are becoming more binding at that stage and additional abatement capacity above that primarily provided by edge-of-field technologies is required.

Table 2. Catchment-level profit for partial movement towards Scenario 1 with constrained land-use change. Bracketed terms constitute costs. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state. Transition denotes benefits or costs arising from land-use transition.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Sector profit							
Dairy	$m	617.53	573.25	557.68	542.16	447.92	450.59
Drystock	$m	210.15	218.30	201.95	202.74	171.13	171.92
Horticulture	$m	28.21	28.77	27.42	21.22	(13.49)	(15.45)
Forest	$m	58.86	63.76	64.38	63.81	65.38	64.99
Transition	$m	0	20.29	21.40	21.80	25.16	21.45
Costs							
Stream fencing	$m	0	(0.26)	(0.83)	(1.95)	(8.18)	(9.40)

Effluent update	$m	0	0	0	0	(2.09)	(2.08)
Soil-conservation plans	$m	0	0	0	(8.76)	(41.37)	(47.24)
Point source (municipal)	$m	0	0	(0.46)	(10.30)	(39.89)	(39.89)
Point source (industrial)		0	(1.27)	(1.58)	(92.41)	(95.17)	(95.17)
Edge-of-field	$m	0	(14.13)	(23.67)	(52.75)	(67.58)	(65.84)
Total profit	*$m*	*914.76*	*888.71*	*846.30*	*685.56*	*441.81*	*433.87*
Loss in profit	*$m*	-	*26.05*	*68.46*	*229.20*	*472.95*	*480.89*
Loss in profit	*%*	-	*3*	*7*	*25*	*52*	*53*

Figure 3 sets out the components of cost for a 25% step towards Scenario 1, in millions of dollars. It can be seen that catchment-level cost, in the case of constrained land-use change, falls mainly on the dairy industry and investment in edge-of-field technologies. Indeed, these components make up around 90% of the total cost imposed on the catchment in this instance. The cost experienced in the dairy sector is associated with both land-use change into less-intensive land uses (e.g. forest) and de-intensification through the use of less fertiliser and supplement and also the adoption of restricted grazing on around 20% of dairy farms. (These activities are discussed in further detail below.)

Figure 3. Division of annual cost ($m) among diverse actions, for a 25% movement towards Scenario 1 with constrained land-use change. The costs represented in this figure are not equivalent to those in the final row of Table 2 because some benefits (e.g. transition income) are also received, but are not shown here.

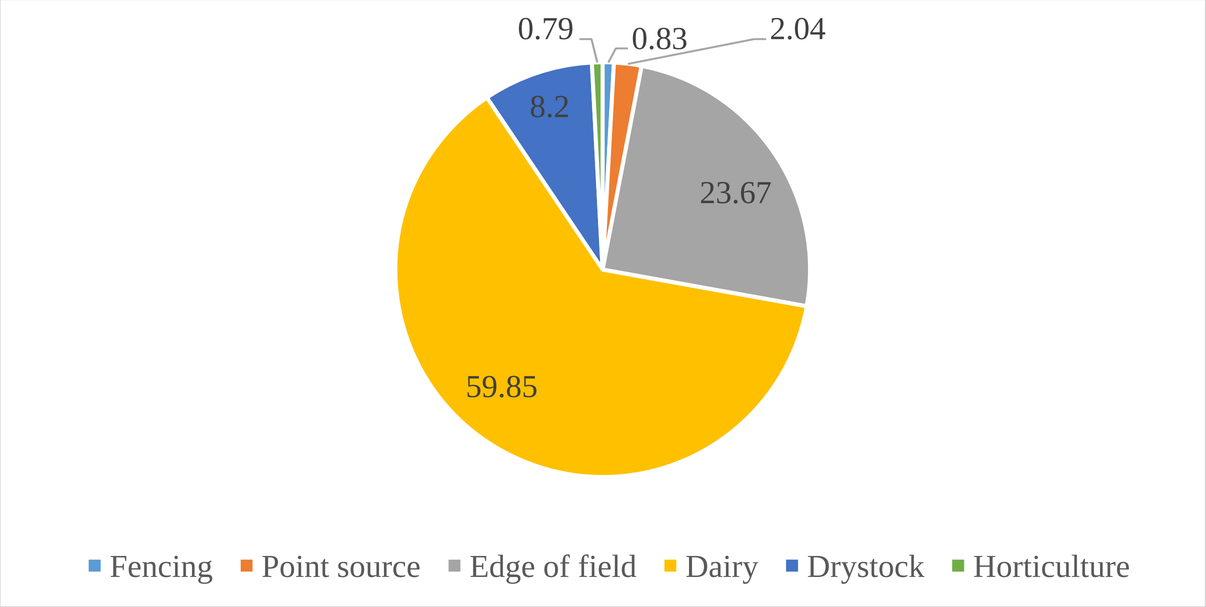


Figure 4 presents the relationship between cost, measured in terms of the loss of catchment profit, and an index of water-quality improvement for the simulations evaluating all steps with constrained land-use change. The index of water-quality improvement is the median percentage improvement, relative to the *current state*, of all attributes measured across all sites. It is evident that as greater movement towards Scenario 1 is achieved—demonstrated in Figure 4 as a movement from left to right—that water quality improves, but also cost increases at an increasing rate. The second most-leftward point is associated with a 10% step; yet, it achieves more than a 10% improvement in water quality, relative to the current state. All other steps achieve a less-than proportional increase in water quality, relative to the current state. The two most-rightward points coalesce because their cost is broadly equivalent, though one is consistent with a significantly-higher number of breaches, as discussed above. Overall, this graph highlights that moderate water-quality improvement—a 15–25% enhancement relative to current state—can be achieved at reasonable cost, compared to the more-stringent scenarios at the right-hand side of the graph.

Figure 4. Relationship between the loss in annual profit ($m) and an index of water-quality improvement. Water-quality improvement is measured in terms of the median percentage improvement, relative to the current state, experienced across all attributes for all sites. Points from left to right are computed for simultaneous shifting of all limits across the catchment 0 (current state), 10, 25, 50, 75, and 100% toward their Scenario 1 level.

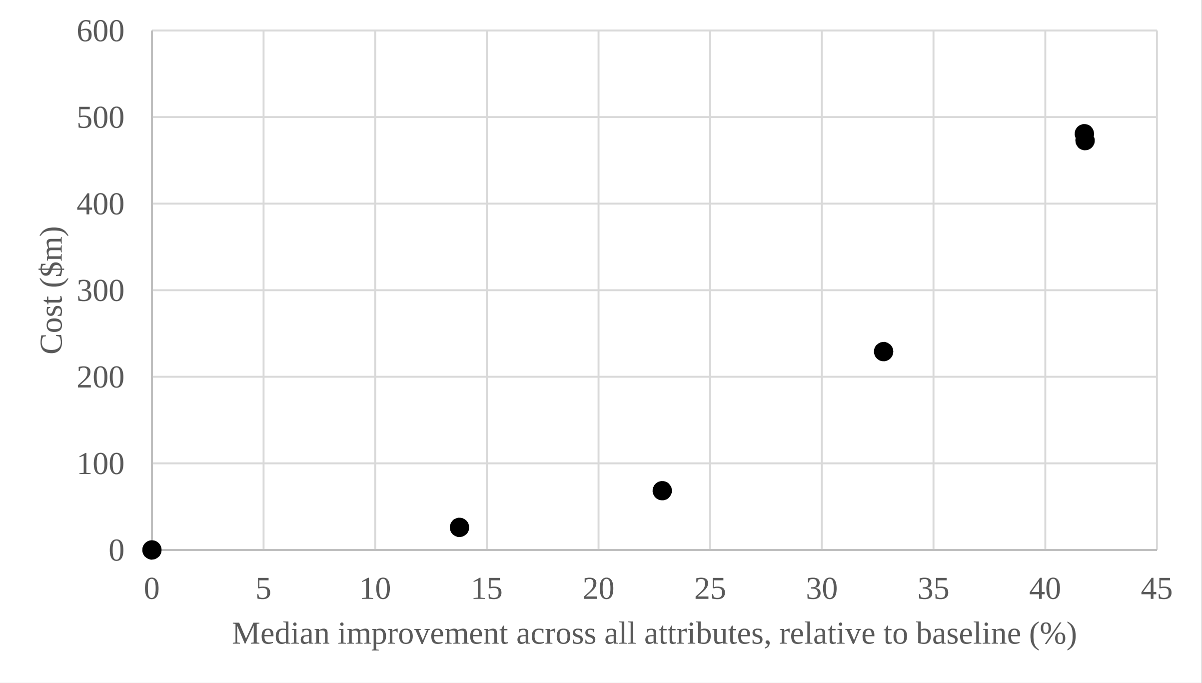


Figure 5 presents the relationship between annual cost, measured in terms of the loss of catchment profit, and the median degree (measured as a percentage) to which the limit for each attribute exceeds that limit defined for Scenario 1. For these simulations, all steps are evaluated using constrained land-use change. The median percentage improvement for each attribute is determined, relative to the *limits set in Scenario 1*. It is evident that as greater movement towards Scenario 1 is achieved—demonstrated in Figure 5 as a movement from left to right—water-quality improves, but cost also increases. This is because greater effort is applied to mitigation effort as the limits become more stringent.

Figure 5. Relationship between the annual loss in catchment-level profit and the median degree (measured as a percentage) to which the limit for each attribute exceeds that limit defined for Scenario 1. A positive exceedance (a breach) means the median limit is above the threshold set in Scenario 1, while a negative exceedance (a net improvement) means the median limit is below this threshold. Points from left to right are computed for the simultaneous shifting of all limits across the catchment 10, 25, 50, 75, and 100% toward their Scenario 1 level.

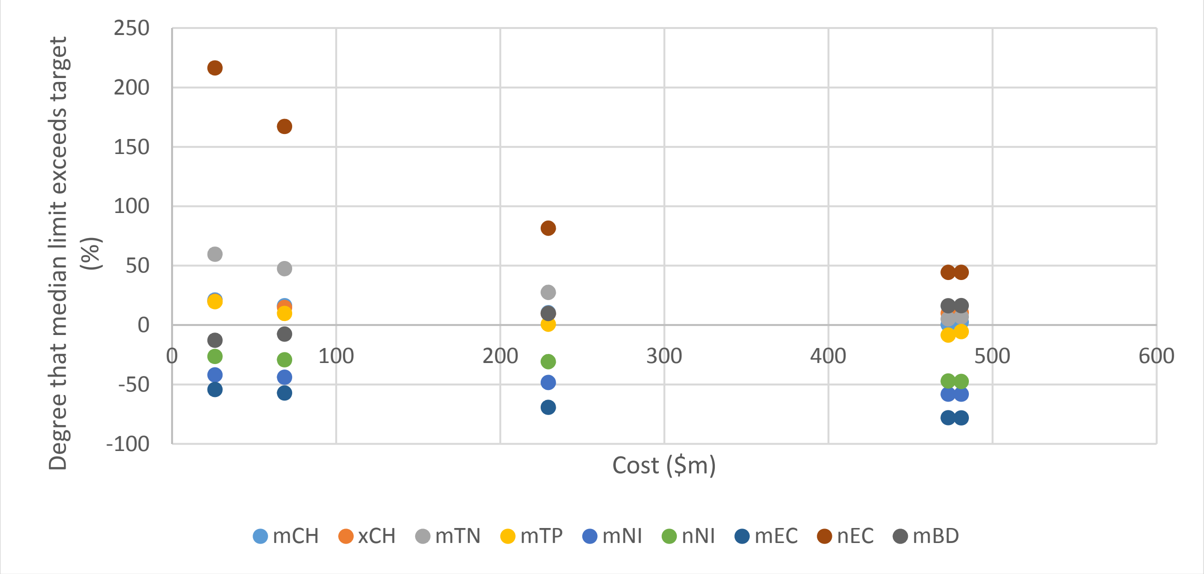


Table 3 identifies that land-use change plays an important role in cost-effective mitigation, even with constrained land-use change, as the goals for water-quality improvement become more stringent. Indeed, around 3–5% of the catchment is subject to land-use change, with around two-thirds of conversion occurring on dairy land. Conversion reaches its maximum at the 75% step, and consequently declines as more-stringent limits are set and the optimisation model is subsequently tasked with trying to minimise cost but also reduce the number of breaches of water-quality limits across the catchment, which are very tight under the Scenario 1 option.

Table 3. Catchment-level land-use allocation for partial movement towards Scenario 1 with constrained land-use change. These values represent the level of one-off land-use transition and not annual expectations. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Dairy	Ha	308,008	288,778	286,408	285,337	282,188	286,611
Drystock	Ha	370,355	375,668	376,635	379,393	378,550	375,004
Horticulture	Ha	6,103	5,951	5,950	5,675	5,636	6,014
Forest	Ha	169,478	183,548	184,952	183,540	187,571	186,316
Dairy to drystock	Ha	0	10,406	16,124	17,961	20,255	15,832
Dairy to forest	Ha	0	8,824	5,476	4,710	5,566	5,566
Drystock to forest	Ha	0	5,246	9,998	9,352	12,527	11,272
Horticulture to drystock	Ha	0	152	154	428	467	89
Total conversion	*Ha*	0	24,628	31,751	32,451	38,815	32,759
Change in land area	*%*	-	3	4	4	5	4

Table 4 reports the production under each simulation. In general, dairy and horticultural production fall steadily with movements towards Scenario 1. For example, dairy production falls by up to 22% and horticultural production falls by up to 44%. Wool and mutton production improve over these scenarios, but lamb and beef production decline. Forestry production improves in response to greater land allocation to this activity (Table 3).

Table 4. Catchment-level annual production for partial movement towards Scenario 1 with constrained land-use change. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Milk solids	t	248,699	228,029	219,570	217,363	190,690	194,285
Wool	t	7,224	8,311	8,272	8,365	7,767	7,639
Mutton	t	15,194	18,812	18,702	18,950	17,307	16,915
Lamb	t	12,334	12,264	12,118	12,185	11,606	11,618
Beef	t	26,059	24,056	23,955	24,147	23,306	23,036
Bull beef	t	15,777	15,394	14,446	14,472	13,569	13,734
Hort. crops	t	251,452	240,766	237,602	211,722	132,135	140,008
S1 logs	M m^3	18	20	20	20	20	20
S2 logs	M m^3	49	53	53	53	54	54
S3 logs	M m^3	52	56	56	56	57	57
Pulp	M m^3	33	36	37	36	37	37
Waste	M m^3	2	2	3	2	3	3

Table 5 reports the use of mitigations as the limits become more stringent. There is consistent replacement of 2-pond systems, stream fencing, riparian buffers, afforestation, erosion control practices on horticultural land, improved phosphorus management, and edge-of-field strategies. The use of these strategies at the 10% and 25% steps highlight their importance as initial strategies for water-quality improvement. Edge-of-field strategies play an increasingly important role in the catchment as limits become more stringent, as indicated by the steady increase in the areas serviced and utilised by these structures throughout the catchment. There seems to be a step-change in the adoption of mitigation practices, as the steps move above 25% in progress towards Scenario 1. In particular, this is observable in the targeted use of farm plans and wide-scale adoption of edge-of-field strategies. In this way, Table 5 shows key information underlying the rapid increase in cost identified for steps above 25% in Figure 1.

Table 5. Catchment-level mitigation use for partial movement towards Scenario 1 with constrained land-use change. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state. This table represents the additional mitigation use that has to occur above the current state to achieve the simulated limits at least cost.

Variable	**Units**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Replacement of 2-pond systems	%	84	88	85	96	96
Uptake of low-rate effluent application	%	0	1	1	13	14
Fencing of Accord streams in dairy	km	2,904	2,931	2,935	2,981	2,991
Fencing of non-Accord streams in dairy	km	871	881	881	935	941
Fencing of streams in drystock	km	2,576	2,744	3,085	4,966	5,335
5m buffers on Accord streams	km	301	329	333	378	388
5m buffers on non-Accord streams	km	186	196	196	251	257
5m buffers on drystock streams	km	5	167	508	2,395	2,764
Land used for 5m buffers on dairy streams	ha	244	263	265	315	323
Land used for 5m buffers on drystock streams	ha	5	167	508	2,395	2,764
Cows on stand-off during autumn/winter	%	11	20	28	76	83
Afforestation of dairy land	ha	8,824	5,476	4,710	5,566	5,566

Afforestation of drystock land	ha	5,246	9,998	9,352	12,527	11,272
Area covered by soil-conservation farm plans	ha	0	0	28,822	139,499	158,743
Use of wheel-track ripping in horticulture	ha	3,052	3,052	3,154	4,084	4,316
Use of decanting bunds in horticulture	ha	3,052	3,052	3,154	4,084	4,316
Improved P mgmt. on dairy farms	%	77	88	77	77	85
Improved P mgmt. on drystock farms	%	91	96	91	91	94
Improved P mgmt. on horticulture farms	%	46	48	46	46	48
Area serviced by detention bund	ha	47,319	94,999	90,956	88,601	86,980
Area serviced by bund+wetland	ha	15,620	39,854	61,187	70,104	66,118
Area serviced by sediment trap	ha	20,745	44,686	51,650	57,621	51,937
Area serviced by small wetland	ha	10,118	27,079	110,786	84,347	88,827
Area serviced by medium wetland	ha	42,548	62,484	140,183	211,744	204,392
Area serviced by detention bund	% of all pasture	7	14	14	13	13
Area serviced by bund+wetland	% of all pasture	4	9	14	16	15
Area serviced by sediment trap	% of all pasture	4	8	9	10	9
Area serviced by small wetland	% of all pasture	1	3	11	8	8
Area serviced by medium wetland	% of all pasture	4	6	13	20	19

Area of utilised by detention bund	ha	0	0	0	0	0
Area utilised by bund+wetland	ha	62	159	245	280	264
Area utilised by sediment trap	ha	41	89	103	115	104
Area utilised by small wetland	ha	40	108	443	337	355
Area utilised by medium wetland	ha	425	625	1,402	2,117	2,044

Table 6 shows the number of breaches identified for each simulation. These breaches are the failure of a particular attribute at that site to reach the limit defined with that simulation. For example, a breach at the 10% step signifies an inability for management to satisfy the proposed limit that is 10% towards Scenario 1 from the base case. If the current state median-nitrate level for a site is 2 g m^{-3} and the Scenario 1 goal for this site is a median-nitrate level of 1 g m^{-3}, then a 10% movement would mean that the new limit is 1.9 g m^{-3}. A breach at this site for the 10% step simulation would mean that the model has been unable to decrease the median-nitrate level at that site beneath 1.9 g m^{-3} (e.g. it is above that level, such as at 1.95 g m^{-3}). A low number of breaches are evident at the 10% and 25% cases. The number of breaches observed increases with each step, but greatly increases within Scenario 1 given that there is a general inability of the simulated set of mitigations to perform additional abatement beyond the level of a 75% step, while land-use patterns remain constrained within those patterns observed historically. This reinforces that while the cost associated with the simulation representing Scenario 1 is significant (Table 2), this representation is still not entirely consistent with the goals set out within the Vision and Strategy, in that a significant number of breaches of attribute limits exist (Table 6). In general, this reflects the general insufficiency of the set of mitigation strategies defined within the model to reach the water-quality aspirations defined in Scenario 1. This is a valuable finding, given that the most-likely and most-effective strategies are defined in the model, and are the result of extensive consultation with industry and scientists. However, it is recognised that adaptation and innovation, especially in response to environmental limits, may lead to the development of mitigation actions that could lead to some breaches being avoided, in reality. Additionally, Table 6 highlights how the number of sites that satisfy the Scenario 1 bands for each attribute increases as goals become more stringent. Overall, it is difficult to achieve the Scenario 1 targets for chlorophyll-a, Total Nitrogen, Total Phosphorus, and 95th percentile *E. coli* concentrations. Clarity is challenging, while the others are relatively much less so.

Table 6. Water quality defined in terms of each attribute, with constrained land-use change. The numbers outside of the brackets are the catchment-level number of breaches for each limit. The numbers inside of the brackets are the percentage of the attribute sites that satisfy the Scenario 1 band in each run. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to the current state.

Indicator	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**	**No. of sites**
Median chlorophyll *a*	0 (22)	0 (22)	0 (44)	2 (44)	4 (56)	9
Maximum chlorophyll *a*	0 (11)	0 (22)	0 (33)	2 (33)	5 (44)	9
Total Nitrogen	0 (11)	1 (11)	3 (22)	3 (33)	6 (33)	9
Total Phosphorus	0 (33)	0 (44)	0 (44)	2 (56)	4 (56)	9
Median nitrate	1 (79)	1 (85)	1 (87)	2 (95)	3 (95)	61
95th percentile nitrate	1 (67)	1 (69)	1 (74)	2 (84)	9 (84)	61
Median *E. coli*	0 (100)	0 (100)	0 (100)	0 (100)	0 (100)	61
95th percentile *E. coli*	0 (26)	2 (30)	5 (36)	22 (39)	37 (39)	61
Black disc (clarity)	2 (29)	2 (48)	6 (62)	10 (67)	11 (81)	58

3.2 Catchment-level output for Case 2, involving limits on TN, current land use for 10% and 25% steps, and unconstrained land use for 50% steps and above

Table 7 shows catchment-level profit for the different steps, but for land-use set at its current management for steps of 10% and 25% and with unconstrained land use for steps of 50%, 75%, and 100%. Sector profit does not change across steps of 10% and 25%, as land use is fixed at its current level. Indeed, these runs are consistent with no de-intensification occurring within these land uses, in contrast to the runs outlined in Section 3.1 where de-intensification is a key driver of reductions in catchment-level profit (Table 2). However, the costs of other mitigations increases significantly, across stream fencing, erosion plans, point-source management, and edge-of-field mitigations. Maintaining land-use management as it is currently motivates greater use of these additional activities, thereby constraining the utilisation of the least-cost approach to mitigation. This imposes a cost that is higher than that outlined in Section 3.1, a cost of 8% and 12% of baseline profit for steps of 10% and 25% respectively, relative to a 3% and 7% cost when land-use management is permitted to change in each sector. In contrast, the cost of achieving 50%, 75%, and 100% steps towards Scenario 1 when land-use is unconstrained is lower than the costs presented in Section 3.1. A cost of 16%, 29%, and 52% of baseline profit is reported for steps of 50%, 75%, and 100%, respectively, with unconstrained land-use change, compared to a 25%, 52%, and 53% cost when land-use management is constrained to lie within historical patterns. Also, the costs of utilising discrete mitigation strategies outside of each land use (as detailed in the *Costs* section of Table 7) decrease, compared to the case where land-use change is constrained, because more mitigation is performed through using land-use change (cf. Table 2 and Table 7). However, these reduced costs require significant upheaval in terms of land use, as observable in the profit streams for each sector in Table 7 and land-use allocation presented below in Table 8.

Table 7. Annual catchment-level profit for partial movement towards Scenario 1, with current land-use patterns observed for 10 and 25% movements, and unconstrained (free) land-use change for 50, 75, and 100% movements. Bracketed terms constitute costs. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Land-use			Current	Current	Free	Free	Free
Sector profit							
Dairy	$m	617.54	617.54	617.54	399.78	259.86	86.01
Drystock	$m	210.15	210.15	210.15	130.70	149.79	119.77
Horticulture	$m	28.21	28.21	28.21	23.74	23.73	(0.31)
Forest	$m	58.86	58.86	58.86	184.66	183.99	183.33
Land use transition	$m	0.00	0.00	0.00	133.35	182.17	224.76
Costs							

Stream fencing	$m	0	(1.94)	(2.05)	(1.11)	(3.09)	(5.68)
Effluent update	$m	0	0	0	0	0	(0.45)
Erosion plans	$m	0	(3.65)	(12.91)	(0.48)	(1.91)	(3.20)
Point source	$m	0	(44.09)	(48.63)	(85.25)	(123.24)	(137.77)
Edge-of-field	$m	0	(25.59)	(48.42)	(16.78)	(22.02)	(24.54)
Total profit	*$m*	*914.76*	*839.50*	*802.75*	*768.60*	*649.28*	*441.92*
Loss in profit	*$m*	-	*75.26*	*112.01*	*146.16*	*265.48*	*472.84*
Loss in profit	*%*	-	*8*	*12*	*16*	*29*	*52*

Table 8 shows that land-use allocation does not change for the 10% and 25% steps, consistent with the characteristics of these simulations. In contrast, the lower cost of the unconstrained land-use change scenarios is attained with enormous change to the baseline land-use patterns. Around 40–50% of land use changes in the model, with substantial proportional losses across both pastoral and horticultural sectors. Indeed, around 43, 63, and 85% of dairy land is lost under the 50, 75, and 100% step scenarios when land-use change is unconstrained. Likewise, the Scenario 1 simulation requires a 64% decrease in horticultural land.

Table 8. Catchment-level land-use allocation for partial movement towards Scenario 1, with current land-use patterns observed for 10 and 25% movements, and unconstrained (free) land-use change for 50, 75, and 100% movements. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state. These values represent the level of one-off land-use transition and not annual expectations.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Land-use			Current	Current	Free	Free	Free
Dairy	Ha	308,008	308,008	308,008	174,961	115,086	48,266
Drystock	Ha	370,355	370,355	370,355	210,882	262,752	330,589
Horticulture	Ha	6,103	6,103	6,103	4,702	4,704	2,230
Forest	Ha	169,478	169,478	169,478	463,401	471,403	472,861
Dairy to drystock	Ha	0	0	0	61,619	99,604	164,499

Dairy to forest	Ha	0	0	0	71,429	79,334	84,927
Drystock to forest	Ha	0	0	0	222,494	208,607	208,139
Horticulture to drystock	Ha	0	0	0	1,401	1,399	3,874
Total conversion	*Ha*	*0*	*0*	*0*	*356,943*	*388,945*	*461,439*
Change in land area	*%*	*0*	*0*	*0*	*42*	*46*	*54*

Table 9 presents the annual production of key output under each of the simulations. Production does not change in the 10% and 25% steps, as land-use management is held constant relative to the baseline. However, when land-use is unconstrained, production levels change markedly. Dairy production falls by 40%, 60%, and 85% for the 50, 75, and 100% steps towards Scenario 1, which is of critical regional importance given that this is the main agricultural industry in the Waikato area. In contrast, forestry production increases substantially as its area increases when land-use change is unconstrained.

Table 9. Catchment-level annual production for partial movement towards Scenario 1, with current land-use patterns observed for 10 and 25% movements, and unconstrained (free) land-use change for 50, 75, and 100% movements. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Variable	**Units**	**Current state**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Land-use			Current	Current	Free	Free	Free
Milk solids	t	248,699	248,699	248,699	150,080	96,089	34,658
Wool	t	7,224	7,224	7,224	4,662	6,088	7,513
Mutton	t	15,194	15,194	15,194	11,610	15,477	18,700
Lamb	t	12,334	12,334	12,334	4,873	5,696	7,074
Beef	t	26,059	26,059	26,059	14,229	19,639	23,082
Bull beef	t	15,777	15,777	15,777	9,513	10,846	8,572
Hort. crops	t	251,452	251,452	251,452	186,834	186,950	62,644

S1 logs	M m^3	18	18	18	62	61	60
S2 logs	M m^3	49	49	49	140	141	142
S3 logs	M m^3	52	52	52	143	145	146
Pulp	M m^3	33	33	33	93	94	94
Waste	M m^3	2	2	2	7	7	7

Table 10 reports the catchment-level mitigation use for each simulation. Mitigation use increases significantly for the 10% and 25% steps, relative to where land-use change in constrained in Section 3.1 (Table 5), because de-intensification on each farm is not permitted within these runs. Significant increases are especially observable for the use of sediment plans and edge-of-field mitigations. In contrast, the simulation of unconstrained land use allows the use of other mitigations to a lesser extent, because of a greater abatement effort being carried out by forestry. For example, edge-of-field mitigations service 13%, 20%, and 19% of the pastoral area with constrained land use for the 50, 75, and 100% steps (Table 5), but this service area decreases to 7, 8, and 10%, respectively, when land-use change is unconstrained (Table 10).

Table 10. Catchment-level mitigation use for partial movement towards Scenario 1, with current land-use patterns observed for 10 and 25% movements, and unconstrained (free) land-use change for 50, 75, and 100% movements. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Variable	**Units**	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**
Land-use		Current	Current	Free	Free	Free
Replacement of 2-pond systems	%	80	80	84	95	85
Uptake of low-rate effluent application	%	0	1	1	1	11
Fencing of Accord streams in dairy	km	2,998	2,998	2,750	2,861	2,907
Fencing of non-Accord streams in dairy	km	938	938	787	841	879

Fencing of streams in drystock	km	3,061	3,095	2,873	3,450	4,226
5m buffers on Accord streams	km	396	396	136	199	83
5m buffers on non-Accord streams	km	254	254	93	110	72
5m buffers on drystock streams	km	489	519	46	816	1,573
Cows on stand-off during autumn/winter	%	0	0	49	58	82
Afforestation of dairy land	ha	0	0	71,429	93,318	95,244
Afforestation of drystock land	ha	0	0	222,494	208,607	208,139
Area covered by erosion farm plans	ha	11,841	42,888	1,727	5,926	10,552
Use of wheel-track ripping in horticulture	ha	3,052	3,057	3,052	3,154	3,154
Use of decanting bunds in horticulture	ha	3,052	3,057	3,052	3,154	3,154
Improved P mgmt. on dairy farms	%	77	77	78	85	97
Improved P mgmt. on drystock farms	%	91	91	95	96	98
Improved P mgmt. on horticulture farms	%	46	46	46	46	48
Area serviced by detention bund	ha	55,572	94,857	12,954	34,714	19,883
Area serviced by bund+wetland	ha	39,416	48,426	14,495	32,224	32,173
Area serviced by sediment trap	ha	63,128	57,666	4,755	10,077	21,132
Area serviced by	ha	29,798	28,938	19,327	28,651	20,573

small wetland						
Area serviced by medium wetland	ha	69,299	153,551	56,297	67,620	82,985
Area serviced by detention bund	% of pasture	8	11	2	4	2
Area serviced by bund+wetland	% of pasture	9	6	2	4	4
Area serviced by sediment trap	% of pasture	12	7	1	1	2
Area serviced by small wetland	% of pasture	3	3	2	3	2
Area serviced by medium wetland	% of pasture	7	18	7	8	10
Area utilised by detention bund	ha	0	0	0	0	0
Area utilised by bund+wetland	ha	158	194	58	129	129
Area utilised by sediment trap	ha	126	115	10	20	42
Area utilised by small wetland	ha	119	116	77	115	82
Area utilised by medium wetland	ha	693	1,536	563	676	830

Table 11 reports the number of breaches for each of these simulations. A high number of breaches are evident for the 10% and 25% steps, reflecting the inability of mitigations defined outside of each farming system to cost-effectively realise the limits defined within these simulations. Sector profit is maintained in the 10% and 25% runs because farm management does not change (Table 7), in contrast to where de-intensification constitutes an important part of cost-effective abatement, corresponding to losses in sector profit, under the constrained land-use scenario (Table 2). Catchment-level profit is beneath the level that can be achieved with simultaneous de-intensification within each sector (Section 3.1) at the goals of 10% and 25%, while the number of breaches is also substantially greater in these circumstances (cf. Table 6 and Table 11). Indeed, the total number of breaches with de-intensification is 4 and 7 for 10% and 25% steps (Table 6), respectively, while the total number without de-intensification is 17 and 18 for the 10% and 25% steps (Table 11).

Table 11. Catchment-level number of breaches for each limit for partial movement towards Scenario 1, with current land-use patterns observed for 10 and 25% movements, and unconstrained (free) land-use change for 50, 75, and 100% movements. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.

Indicator	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**	**75% of Sc. 1**	**Sc. 1**	**No. of sites**
Land-use	Current	Current	Free	Free	Free	
Median chlorophyll *a*	0	0	0	0	4	9
Max. chlorophyll *a*	0	0	0	0	4	9
Total Nitrogen	0	0	0	2	3	9
Total Phosphorus	6	5	0	0	3	9
Median nitrate	1	2	0	0	0	61
95th percentile nitrate	5	4	0	0	2	61
Median *E. coli*	5	5	0	0	0	61
95th percentile *E. coli*	0	0	5	11	22	61
Black disc (clarity)	0	2	5	10	10	58

Table 12 reports the regional and national impacts of the 10% and 25% steps, where land use is fixed at its current activity. De-intensification is not investigated; however, costs still fall on individual sectors associated with the implementation of a broad range of mitigations (e.g. edge-of-field structures, farm plans, and stream fencing) within these enterprises. Moreover, these abatement practices are used to an inflated extent, relative to the constrained land-use scenario (Section 3.1), because de-intensification cannot perform its key role in cost-effective mitigation. That is, the cheaper abatement associated with de-intensification is not utilised; rather, the other mitigations (e.g. edge-of-field practices) are used past the point that diminishing returns set in. The net result is that there is some further detrimental effects identified at the regional and national level, though these are slight in terms of the total value of the regional and national economies as a whole.

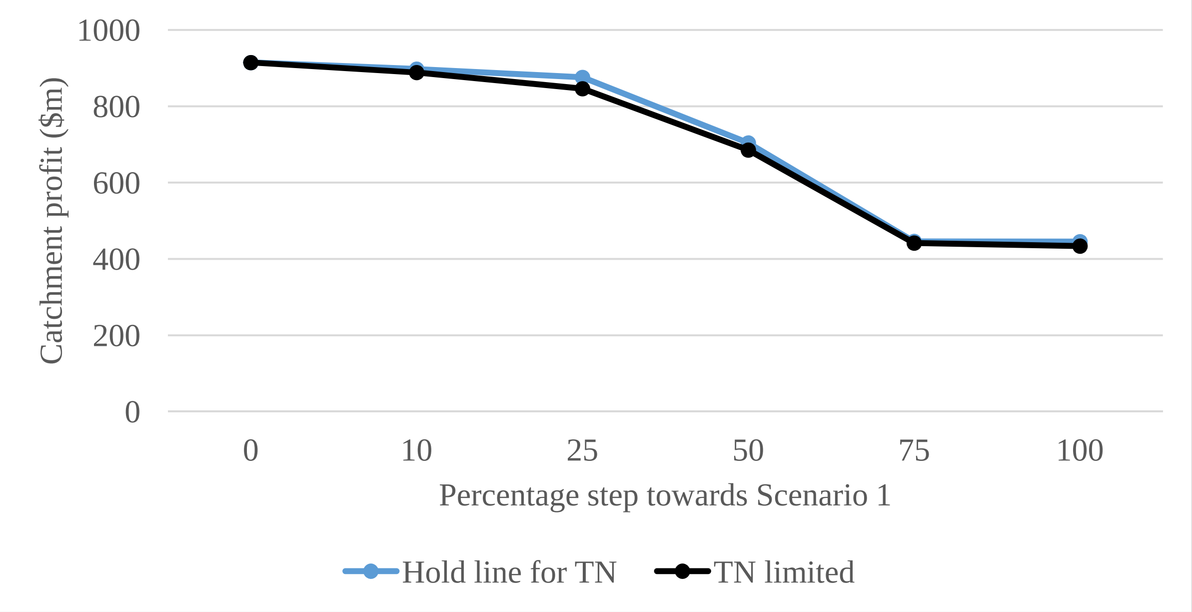
Table 12. Waikato region and national impacts of 10% and 25% steps, with land use fixed at its current activity.

Industry	**Waikato region**						**New Zealand**					
	Val add ($m)		**Jobs (MEC)**		**Export ($m)**		**Val. add ($m)**		**Jobs (MEC)**		**Export ($m)**	
	10%	**25%**	**10%**	**25%**	**10%**	**25%**	**10%**	**25%**	**10%**	**25%**	**10%**	**25%**
Horticulture	0	0	0	0	0	0	0	0	-2	-3	0	0
Sheep, beef, and grain	-4	-12	-4	-4	0	0	-5	-12	-8	-12	0	0
Dairy farming	-8	-13	-34	-68	0	0	-9	-15	-44	-89	0	0
Forestry	0	0	0	0	0	0	0	0	0	0	0	0
Other primary	0	1	4	9	0	0	1	2	5	11	0	0
Agriculture and forestry support	0	1	9	10	0	0	1	1	20	21	0	0
Meat and meat product manufacturing	0	0	-1	-3	-1	-1	0	-1	-4	-6	-1	-2
Dairy product manufacturing	-1	-2	-3	-7	-5	-9	-2	-3	-6	-11	-7	-13
Wood and paper manufacturing	0	0	0	0	0	0	0	0	0	0	0	0
Other manufacturing	0	0	1	3	0	0	0	1	-1	5	0	0
Utilities	2	3	6	6	0	0	3	3	6	7	0	0
Construction	0	0	-3	8	0	0	-1	0	-13	0	0	0
Wholesale and retail trade	-1	-1	-25	-32	0	0	-2	-3	-46	-59	0	0
Transport	0	0	0	0	0	0	0	0	-1	-3	0	0
Professional/administrative services	4	5	62	71	0	0	10	11	132	150	0	0
Local and central government	0	-1	-5	-6	0	0	-1	-2	-13	-18	0	0
Other services	-7	-9	-70	-96	0	0	-9	-12	-92	-133	0	0
Total change relative to current state	-14	-29	-64	-108	-5	-10	-14	-31	-66	-139	-8	-15

3.3 Catchment-level output for Case 3, involving TN being held below or at its current level and constrained land-use change

Figure 6 shows catchment-level profit for steps denoting partial movement towards Scenario 1, with land-use change constrained to be within those patterns observed historically. There is little difference between the curves. This shows that a major reduction in TN is required to best reach each step, regardless of whether or not TN is constrained in the model. This finding arises from the fact that the primary mitigation strategies (e.g. de-intensification, stream fencing, point-source improvement, and edge-of-field strategies) have concomitant benefits for reducing both nitrogen and phosphorus loads. The main abatement strategies that focus on P, with little benefit for mitigation N loss, are improved phosphorus management and sediment plans for managing farm erosion. These are valuable practices, but do not achieve sufficient P mitigation by themselves to warrant the exclusion of practices that have benefits for N loss also. Experiments with the model show that nitrate limits are not a major driver, either.

Figure 6. Catchment-level profit for partial movement towards Scenario 1, with TN limited according to each step ("TN limited") or held at or beneath its current state ("Hold line for TN"). These runs are performed with constrained land-use change. 10, 25, 50, and 75% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, 50, and 75% of the way toward their Scenario 1 level, relative to current state.



3.4 Regional and national-level impacts of simulated steps with constrained land use

Tables 13–30 outline the impacts of the 10, 25, and 50% steps towards Scenario 1 at the regional, national, and FMU scales. The focus of this section is on the smaller movements towards Scenario 1 investigated in this report because (a) the CSG has identified that these are more pertinent than more-stringent goals to guide initial steps towards water-quality improvement, (b) these are more consistent with the economic conditions for which the regional input-output model is constructed to represent, and (c) the regional- and national-level costs of more-stringent goals for water quality are described extensively in the first report involving the economic evaluation of CSG scenarios.

Several key findings are evident below:

1. Movements towards achieving water-quality improvement, no matter what degree is simulated, constitutes overall reductions in value-added, employment, and net exports across the catchment. The 10, 25, and 50% steps towards Scenario 1 lead to a reduction in value added of $101m, $164m, and $221m in the Waikato region, respectively, and lead to the loss of around 1,198; 1,954; and 2,389 jobs, as well. Nationally, the 10, 25, and 50% steps towards Scenario 1 are predicted to yield a reduction in value added of $212m, $339m, and $438m nationally, respectively, and lead to the loss of around 2,276; 3,742; and 4,684 jobs.
2. The degree to which value-added, employment, and net exports change across each FMU differs, depending on the relative importance of the sectors most affected within a given simulation and the way that mitigation use varies across space within a given plan to achieve the simulated limits at least cost (Section 3.5).
3. The main industries that are detrimentally affected by water-quality improvement are the dairy; sheep, beef, and grain; and horticultural industries. The 25% and 50% steps towards Scenario 1 lead to a reduction in value added in the dairy industry of $101m and $127m in the Waikato region, respectively, and lead to the loss of around 1,309 and 1,450 jobs in this sector, as well. The 25% and 50% steps towards Scenario 1 lead to a reduction in value added in the sheep, beef, and grain industry of $5m and $17m in the Waikato region, respectively, and lead to the loss of around 122 and 109 jobs in this sector, as well. The 25% and 50% steps towards Scenario 1 lead to a reduction in

value added in the horticultural industry of $3m and $10m in the Waikato region, respectively, and lead to the loss of around 122 and 253 jobs in this sector, as well.

4. The negative economic impacts experienced within agricultural sectors flow onto the processing, utility, retail, and transport sectors.
5. Water-quality improvement in the Waikato and Waipa River catchments are predicted to have a detrimental impact on net international exports from this region and at the national level. Detrimental impacts are concentrated in the dairy sector, making up most of the reductions experienced at the regional and national level. In contrast, wood and paper manufacturing benefit from the expansion of the forestry sector in these simulations.

Table 13. Impacts on value added ($m), relative to the baseline, in the entire Waikato region with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-2	-3	-10
Sheep, beef, and grain	5	-5	-17
Dairy farming	-73	-101	-127
Forestry	8	9	8
Other primary	0	0	1
Agriculture and forestry support	-4	-5	-5
Meat and meat product manufacturing	4	3	3
Dairy product manufacturing	-31	-41	-46
Wood and paper manufacturing	8	8	8
Other manufacturing	-1	-2	-3
Utilities	0	-1	6
Construction	1	1	-6
Wholesale and retail trade	-2	-3	-6
Transport	-1	-2	-2
Professional/administrative services	-1	-2	7
Local and central government	0	-1	-1
Other services	-10	-18	-29
Total loss relative to baseline	-101	-164	-221

Table 14. Impacts on employment (Modified Employee Counts), relative to the baseline, in the entire Waikato region with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	10% of Sc. 1	25% of Sc. 1	50% of Sc. 1
Horticulture	-94	-122	-253
Sheep, beef, and grain	98	-122	-109
Dairy farming	-1,008	-1,309	-1,450
Forestry	70	78	70
Other primary	0	-2	5
Agriculture and forestry support	-65	-96	-98
Meat and meat product manufacturing	36	21	21
Dairy product manufacturing	-104	-138	-154
Wood and paper manufacturing	58	64	58
Other manufacturing	-8	-14	-29
Utilities	-2	-4	13
Construction	14	17	-88
Wholesale and retail trade	-44	-73	-127
Transport	-11	-18	-22
Professional/administrative services	-24	-36	93
Local and central government	-6	-11	-19
Other services	-107	-189	-304
Total loss relative to baseline	-1,198	-1,954	-2,389

Table 15. Impacts on net international exports ($m), relative to the baseline, in the entire Waikato region with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	10% of Sc. 1	25% of Sc. 1	50% of Sc. 1
Horticulture	-2	-3	-9
Sheep, beef, and grain	1	-1	-1

Dairy farming	-1	-2	-2
Forestry	2	2	2
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	14	8	8
Dairy product manufacturing	-139	-184	-205
Wood and paper manufacturing	15	17	15
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	-110	-163	-192

Table 16. Impacts on value added ($m), relative to the baseline, in New Zealand with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-3	-6	-13
Sheep, beef, and grain	7	-7	-19
Dairy farming	-113	-153	-184
Forestry	11	12	11
Other primary	-1	-1	-1
Agriculture and forestry	-10	-15	-16

support			
Meat and meat product manufacturing	8	4	4
Dairy product manufacturing	-49	-64	-72
Wood and paper manufacturing	12	13	12
Other manufacturing	-12	-18	-41
Utilities	-2	-4	2
Construction	0	0	-12
Wholesale and retail trade	-9	-15	-24
Transport	-6	-11	-14
Professional/administrative services	-11	-17	7
Local and central government	-2	-4	-6
Other services	-31	-51	-71
Total loss relative to baseline	-212	-339	-438

Table 17. Impacts on employment (Modified Employee Counts), relative to the baseline, in New Zealand with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-133	-201	-362
Sheep, beef, and grain	123	-152	-141
Dairy farming	-1,347	-1,760	-1,944
Forestry	83	90	81
Other primary	-4	-12	-9
Agriculture and forestry support	-198	-296	-314
Meat and meat product manufacturing	74	42	40
Dairy product manufacturing	-182	-241	-269

Wood and paper manufacturing	102	112	102
Other manufacturing	-96	-164	-434
Utilities	-7	-11	4
Construction	5	-3	-182
Wholesale and retail trade	-153	-252	-414
Transport	-76	-125	-159
Professional/administrative services	-169	-267	44
Local and central government	-28	-48	-71
Other services	-270	-456	-656
Total loss relative to baseline	-2,276	-3,742	-4,684

Table 18. Impacts on net international exports ($m), relative to the baseline, in New Zealand with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-2	-3	-9
Sheep, beef, and grain	1	-1	-1
Dairy farming	-1	-2	-2
Forestry	2	2	2
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	22	12	12
Dairy product manufacturing	-206	-273	-304
Wood and paper manufacturing	20	22	20
Other manufacturing	1	-2	-17
Utilities	0	0	0

Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	-164	-243	-298

Table 19. Impacts on value added ($m), relative to the baseline, in the Lower Waikato (Ngaruawahia to Port Waikato) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-1	-1	-6
Sheep, beef, and grain	2	0	-7
Dairy farming	-6	-10	-18
Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	0	0	0
Dairy product manufacturing	0	0	0
Wood and paper manufacturing	0	0	0
Other manufacturing	0	0	0
Utilities	0	-1	-1
Construction	0	0	1
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative	0	0	0

services			
Local and central government	0	0	0
Other services	0	-1	-3
Total loss relative to baseline	-7	-13	-35

Table 20. Impacts on employment (Modified Employee Counts), relative to the baseline, in the Lower Waikato (Ngaruawahia to Port Waikato) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-51	-51	-142
Sheep, beef, and grain	41	37	35
Dairy farming	-132	-155	-188
Forestry	2	2	2
Other primary	0	0	2
Agriculture and forestry support	-6	-7	-7
Meat and meat product manufacturing	2	1	1
Dairy product manufacturing	-1	-1	-1
Wood and paper manufacturing	2	2	2
Other manufacturing	0	0	-2
Utilities	0	-1	-1
Construction	2	4	10
Wholesale and retail trade	-2	-3	-6
Transport	-1	-2	-2
Professional/administrative services	-1	-1	1
Local and central government	0	0	-1
Other services	-4	-9	-27

Total loss relative to baseline	-150	-184	-324

Table 21. Impacts on net international exports ($m), relative to the baseline, in the Lower Waikato (Ngaruawahia to Port Waikato) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-1	-1	-4
Sheep, beef, and grain	0	0	0
Dairy farming	0	0	0
Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	1	0	0
Dairy product manufacturing	-1	-1	-1
Wood and paper manufacturing	0	0	0
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	-1	-1	-5

Table 22. Impacts on value added ($m), relative to the baseline, in the Waipa FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the

catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	0	0	0
Sheep, beef, and grain	2	1	-2
Dairy farming	0	-5	-11
Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	0	-1	-1
Meat and meat product manufacturing	1	0	0
Dairy product manufacturing	-3	-5	-6
Wood and paper manufacturing	0	0	0
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	-1	-3
Total loss relative to baseline	-3	-11	-23

Table 23. Impacts on employment (Modified Employee Counts), relative to the baseline, in the Waipa FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc.**	**25% of Sc.**	**50% of Sc.**

	1	1	1
Horticulture	0	0	0
Sheep, beef, and grain	24	24	23
Dairy farming	0	-58	-83
Forestry	0	0	0
Other primary	0	0	1
Agriculture and forestry support	-9	-17	-14
Meat and meat product manufacturing	7	4	4
Dairy product manufacturing	-12	-16	-19
Wood and paper manufacturing	1	1	1
Other manufacturing	-1	-1	-2
Utilities	-1	-1	-1
Construction	0	2	1
Wholesale and retail trade	-3	-6	-11
Transport	-1	-2	-3
Professional/administrative services	-3	-4	2
Local and central government	-1	-2	-3
Other services	-3	-11	-25
Total loss relative to baseline	-1	-86	-129

Table 24. Impacts on net international exports ($m), relative to the baseline, in the Waipa FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	10% of Sc. 1	25% of Sc. 1	50% of Sc. 1
Horticulture	0	0	0
Sheep, beef, and grain	0	0	0
Dairy farming	0	0	0

Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	2	2	1
Dairy product manufacturing	-16	-22	-25
Wood and paper manufacturing	0	0	0
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	-13	-20	-23

Table 25. Impacts on value added ($m), relative to the baseline, in the mid-Waikato (Karapiro to Ngaruwahia) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	0	0	0
Sheep, beef, and grain	0	0	0
Dairy farming	0	-1	-3
Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	-1	-1	-1

Meat and meat product manufacturing	1	1	1
Dairy product manufacturing	-11	-15	-17
Wood and paper manufacturing	0	0	0
Other manufacturing	-1	-1	-1
Utilities	0	0	0
Construction	0	0	-1
Wholesale and retail trade	-1	-2	-3
Transport	0	-1	-1
Professional/administrative services	-1	-1	3
Local and central government	0	0	-1
Other services	-3	-5	-11
Total loss relative to baseline	-17	-26	-34

Table 26. Impacts on employment (Modified Employee Counts), relative to the baseline, in the mid-Waikato (Karapiro to Ngaruwahia) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-32	-32	-33
Sheep, beef, and grain	4	4	4
Dairy farming	-3	-17	-32
Forestry	0	0	0
Other primary	0	0	1
Agriculture and forestry support	-14	-19	-19
Meat and meat product manufacturing	11	7	7
Dairy product manufacturing	-38	-50	-57
Wood and paper	3	3	3

manufacturing			
Other manufacturing	-7	-10	-17
Utilities	-2	-2	-1
Construction	1	2	-6
Wholesale and retail trade	-17	-29	-56
Transport	-5	-8	-9
Professional/administrative services	-20	-29	45
Local and central government	-3	-5	-10
Other services	-34	-63	-126
Total loss relative to baseline	-154	-249	-307

Table 27. Impacts on net international exports ($m), relative to the baseline, in the mid-Waikato (Karapiro to Ngaruwahia) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	0	0	0
Sheep, beef, and grain	0	0	0
Dairy farming	0	0	0
Forestry	0	0	0
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	4	2	2
Dairy product manufacturing	-49	-65	-73
Wood and paper manufacturing	1	1	1
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0

Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	-45	-62	-71

Table 28. Impacts on value added ($m), relative to the baseline, in the Upper Waikato (Karapiro to Taupo Gates) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	0	-1	-3
Sheep, beef, and grain	1	-6	-7
Dairy farming	-52	-66	-74
Forestry	7	8	7
Other primary	0	0	0
Agriculture and forestry support	-1	-2	-2
Meat and meat product manufacturing	0	0	0
Dairy product manufacturing	-3	-4	-5
Wood and paper manufacturing	7	7	7
Other manufacturing	0	0	0
Utilities	0	0	7
Construction	1	0	-4
Wholesale and retail trade	0	-1	-1
Transport	0	0	0
Professional/administrative services	0	0	2

Local and central government	0	0	0
Other services	-5	-7	-8
Total loss relative to baseline	-46	-72	-83

Table 29. Impacts on employment (Modified Employee Counts), relative to the baseline, in the Upper Waikato (Karapiro to Taupo Gates) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	-10	-36	-74
Sheep, beef, and grain	27	-182	-167
Dairy farming	-732	-892	-946
Forestry	64	71	64
Other primary	0	-1	-1
Agriculture and forestry support	-24	-34	-37
Meat and meat product manufacturing	1	1	1
Dairy product manufacturing	-11	-14	-15
Wood and paper manufacturing	47	52	47
Other manufacturing	1	0	-3
Utilities	1	1	16
Construction	8	8	-62
Wholesale and retail trade	-10	-17	-24
Transport	-1	-2	-2
Professional/administrative services	2	2	30
Local and central government	-1	-2	-2
Other services	-46	-73	-81
Total loss relative to baseline	-685	-1,117	-1,257

Table 30. Impacts on net international exports ($m), relative to the baseline, in the Upper Waikato (Karapiro to Taupo Gates) FMU with constrained land-use change. 10, 25, and 50% of Scenario 1 denote that all limits across the catchment are simultaneously shifted 10, 25, and 50% of the way toward their Scenario 1 level, relative to current state.

Industry	**10% of Sc. 1**	**25% of Sc. 1**	**50% of Sc. 1**
Horticulture	0	-1	-4
Sheep, beef, and grain	0	-2	-2
Dairy farming	-1	-1	-1
Forestry	2	2	2
Other primary	0	0	0
Agriculture and forestry support	0	0	0
Meat and meat product manufacturing	1	0	0
Dairy product manufacturing	-15	-19	-21
Wood and paper manufacturing	14	15	14
Other manufacturing	0	0	0
Utilities	0	0	0
Construction	0	0	0
Wholesale and retail trade	0	0	0
Transport	0	0	0
Professional/administrative services	0	0	0
Local and central government	0	0	0
Other services	0	0	0
Total loss relative to baseline	0	-6	-12

3.5 Spatial implications of cost-effective mitigation with constrained land-use change

This section involves the presentation and discussion of various maps of the catchment that show how key results from the economic modelling vary across each sub-catchment and

FMU. All results reported in this section have been generated with *constrained land-use change*.

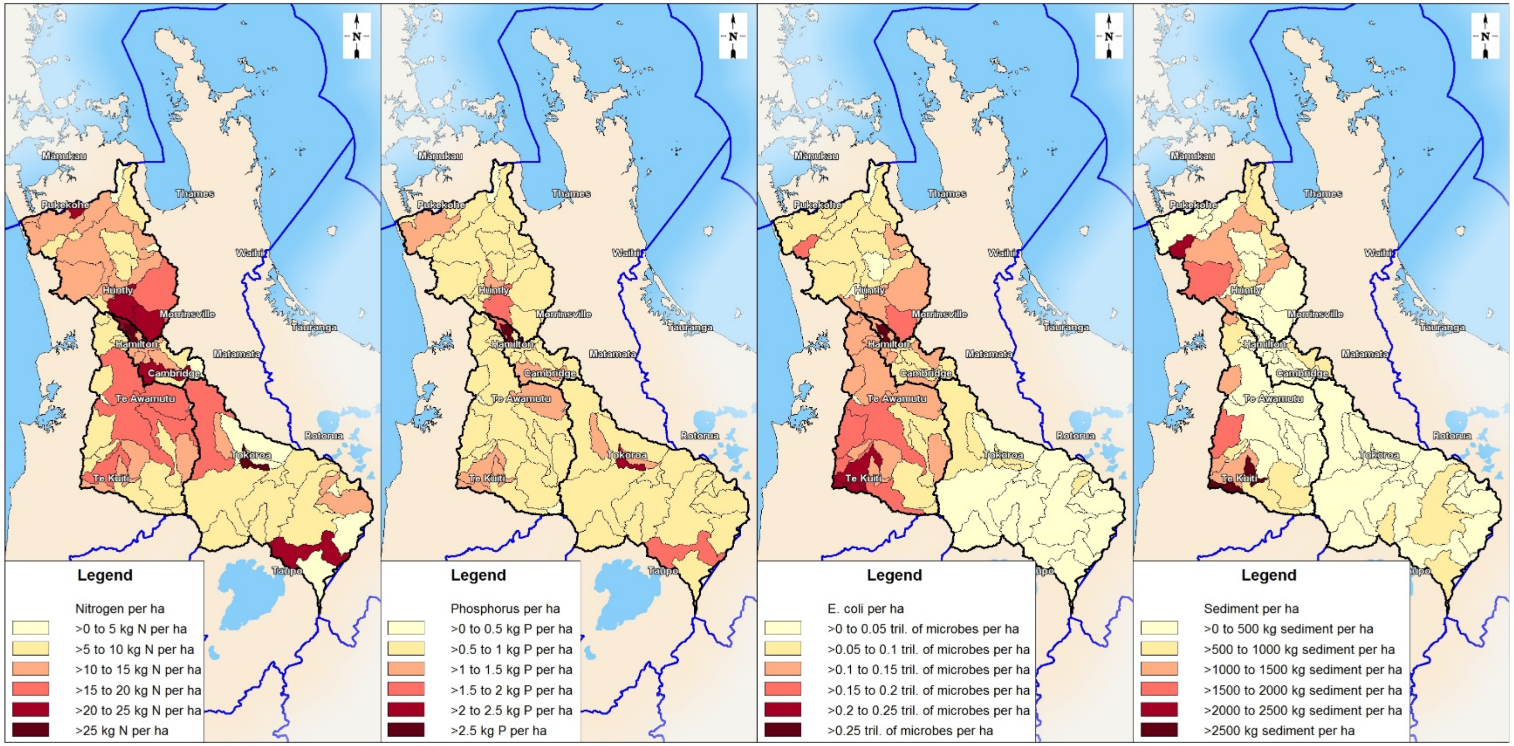
Figure 7 shows how the baseline loads of each contaminant vary by sub-catchment and FMU. This is important because it indicates why cost-effective mitigation relies on implementing diverse mitigation strategies to differing degrees for different contaminants across space.

Figure 8 shows the effect of movements towards Scenario 1, in terms of the impact on sub-catchment profit (constituting all of those costs presented in Table 2). First, it is notable how cost varies across space, as cost-effective mitigation requires more abatement in some areas. Nevertheless, almost all sub-catchments experience a loss in the Scenario 1 simulation. Second, it is obvious how the extent to which profit decreases with abatement across the catchment becomes more obvious as Scenario 1 is approached (i.e. as we move left to right in Figure 8).

Figures 9, 10, 11, and 12 present the % reduction in sub-catchment loads required for each step for nitrogen, phosphorus, microbes, and sediment. These highlight a number of key factors. First, the areas of focus differ for each contaminant. This reflects diversity in the key sources, attenuation, and cost-effectiveness of mitigation activities for each contaminant. Second, greater % reductions in the load of each contaminant are observed as limits become more stringent. Third, some small increases at given sites are experienced, as reductions in loading at one sub-catchment creates headroom for expansion in another. Fourth, mitigation across almost all of the catchment occurs at the 75% and 100% steps, though the level of intensity varies by site. Fifth, an increase in nitrogen loss is evident for a small sub-catchment on the eastern side of the Upper Waikato, across all runs (Figure 9). This is an artefact of the modelling, in that the estimated ultimate attenuation rate for nitrogen is so high that no amount of de-intensification can prevent a breach for nitrate occurring at this site. Last, an increase in microbial loss is observed for a long narrow sub-catchment in the middle of the catchment in Figure 11. This is a main-stem site and intensification is possible, without breaching the defined limit for related attributes in this sub-catchment, because of mitigation occurring upstream. This is aided by high attenuation rates for microbes, relative to nutrients, given that they are biological organisms.

Figures 13 and 14 present the extent of breaches evident in model output for the 95th percentile measurement of microbial loads and the median measurement of clarity, respectively. The number of breaches is more evident for the 75% and 100% limits, as discussed above. This is similar across both figures. However, most breaches are evident in the Lower Waikato FMU and Waipa FMU for microbes, but are observed across the entire catchment for clarity. These results reflect diversity in the baseline loads of each contaminant, the attenuation of each contaminant across the flow network, and spatial differences in the goals for each contaminant.

Figure 7. Baseline loads of each contaminant across each sub-catchment in the study region.



Baseline data (load per ha)
Constrained land-use change

Created by: A Jeffries
Projection: NZTM
Map Date: 11/09/2015
Model Data Date: 11/09/2015

Map Status: Version 1
Request No.: 30794
Workspace name:
30794_Baseline_Data.gws

0 50 100 150 200
Kilometres
Scale - 1:1,700,000 at A3

A3

Healthy Rivers | Wai Ora
PLAN FOR CHANGE | HE RAUTAKI WHAKAPAIPAI

Legend

▭ Freshwater management units
▭ Waikato regional boundary

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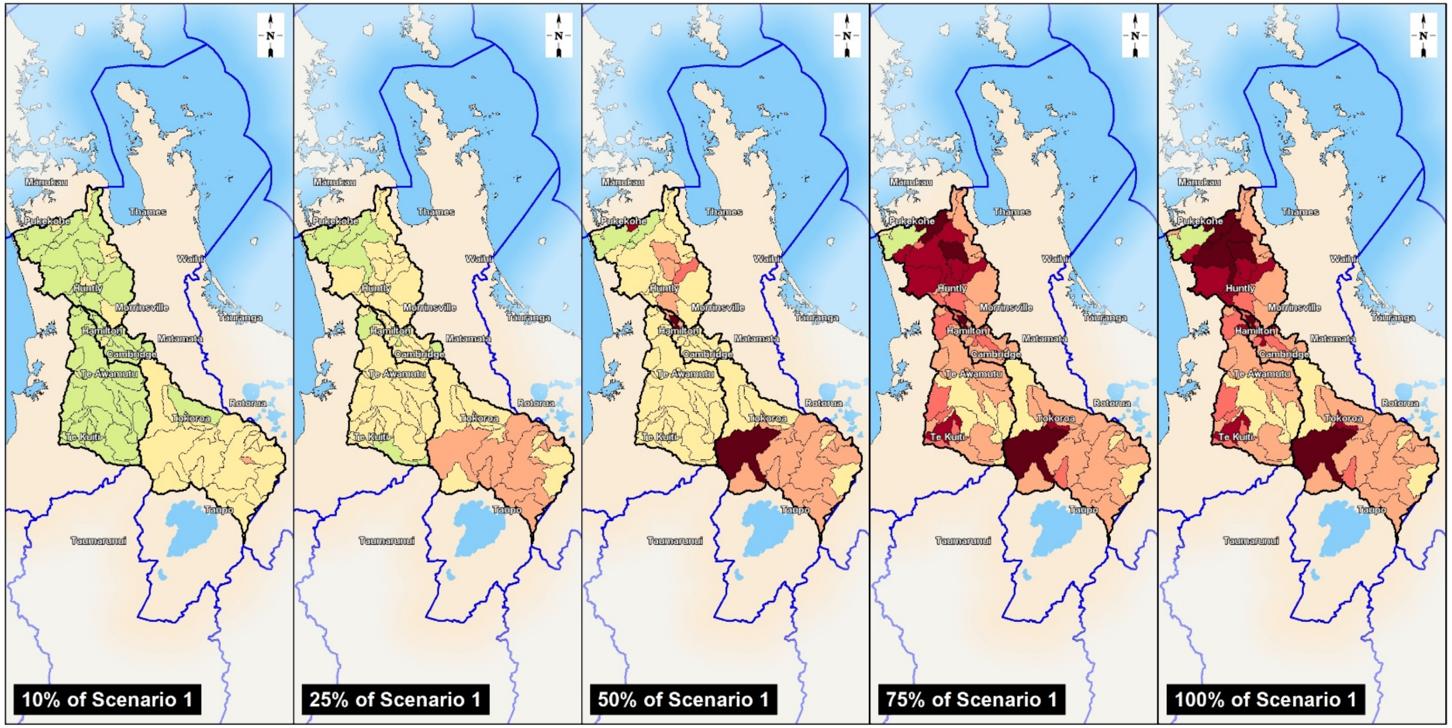
Digital Boundary Data sourced from Statistics New Zealand.

Figure 8. Change in total profit in each sub-catchment, for constrained land-use change.



Change in total profit within a subcatchment (%)

Land-use constrained to be within historical patterns

Created by: A Jeffries
Projection: NZTM
Map Date: 11/09/2015
Model Data Date: 11/09/2015

Map Status: Version 1
Request No.: 30794
Workspace name:
30794_Change_in_Total_Profit.gws

0 50 100 150 200 250
Kilometres
Scale - 1:2,100,000 at A3

A3

Healthy Rivers | Wai Ora
PLAN FOR CHANGE | HE RAUTAKI WHAKAPAIPAI

Legend

Change in total profit (%)

🟩	>100%
🟩	>75% to 100%
🟩	>50% to 75%
🟩	>25% to 50%
🟩	>0% to 25%
🟨	0% (no change)
🟨	<0% to -25%
🟧	<-25% to -50%
🟥	<-50% to -75%
🟥	<-75% to -100%
🟥	<-100%
☐	Freshwater management unit boundaries
☐	Waikato regional boundary

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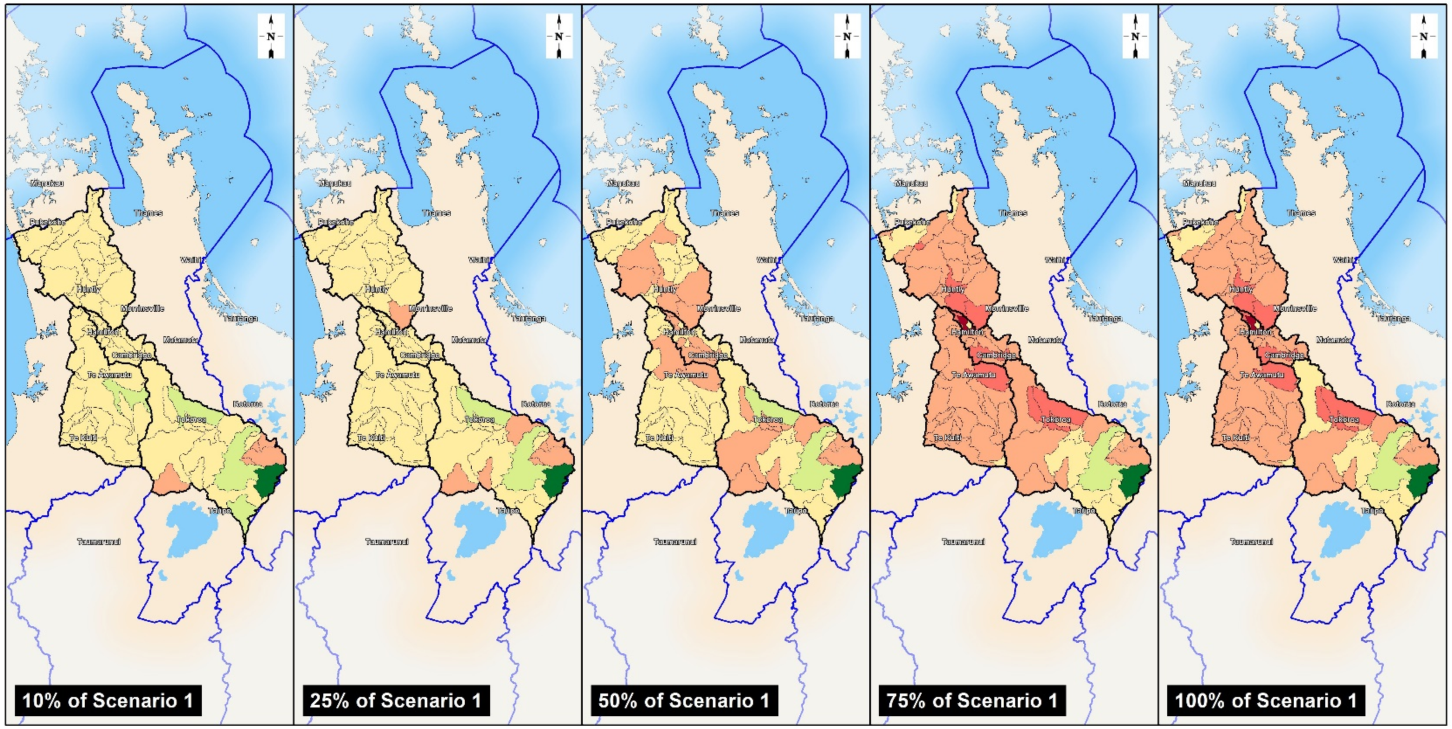
Digital Boundary Data sourced from Statistics New Zealand.

Figure 9. Change in nitrogen loads in each sub-catchment, for constrained land-use change.



Change in load of nitrogen within a subcatchment (%)

Land-use constrained to be within historical patterns

Created by: RMG
Projection: NZTM
Map Date: 14/09/2015
Model Data Date: 11/09/2015

Map Status: Version 1
Request No.: 30794
Workspace name:
30794_Change_in_load_of_nitrogen.mxd

0 50 100 150 200 250
Kilometres
Scale - 1:2,100,000 at A3

A3

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PLAN FOR CHANGE | HE RAUTAKI WHAKAPAIPAI

Legend
Change in load of nitrogen within a subcatchment (%)

▢	0%	🟩	>0% to 25%
▨	<0% to -25%	🟩	>25% to 50%
🟧	<-25% to -50%	🟩	>50% to 75%
🟥	<-50% to -75%	🟩	>75% to 100%
🟥	<-75% to -100%	🟩	>100%
🟫	<-100%	☐	Freshwater management unit boundaries
		☐	Waikato regional boundary

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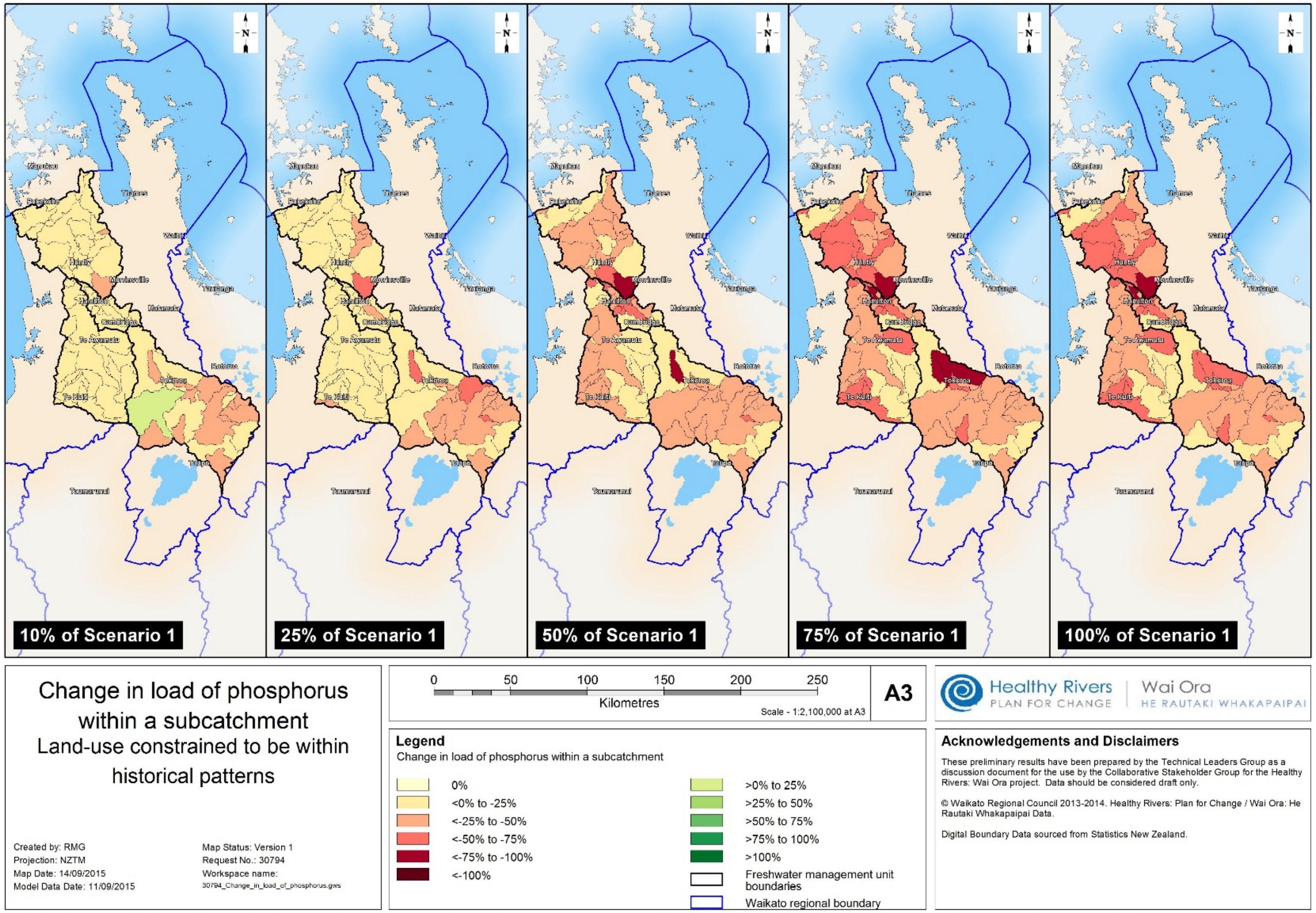
Digital Boundary Data sourced from Statistics New Zealand.

Figure 10. Change in phosphorus loads in each sub-catchment, for constrained land-use change.



Created by: RMG
Projection: NZTM
Map Date: 14/09/2015
Model Data Date: 11/09/2015

Map Status: Version 1
Request No.: 30794
Workspace name:
30794_Change_in_load_of_phosphorus.gws

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Digital Boundary Data sourced from Statistics New Zealand.

Figure 11. Change in microbial loads in each sub-catchment, for constrained land-use change.

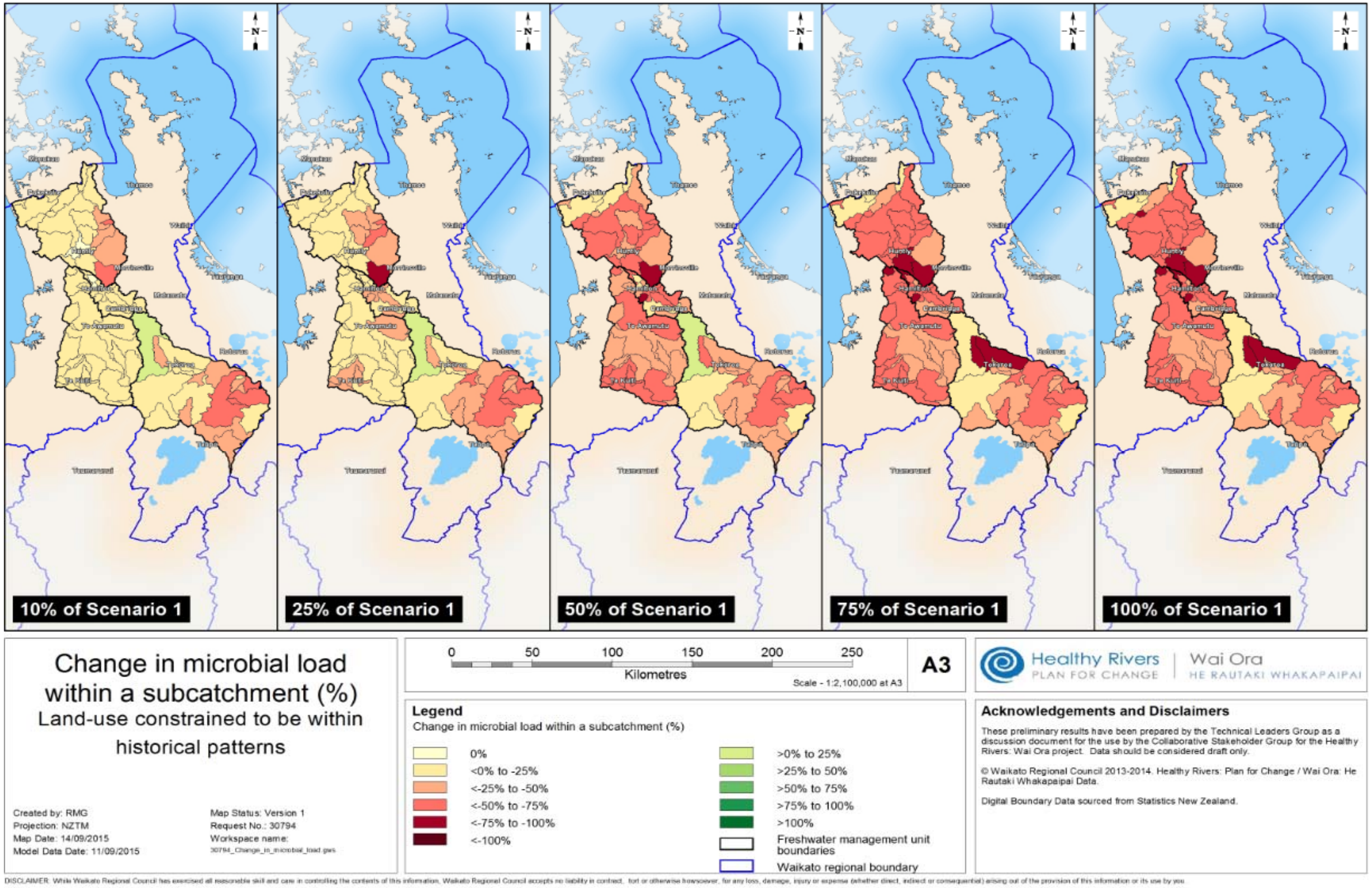

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Figure 12. Change in sediment loads in each sub-catchment, for constrained land-use change.

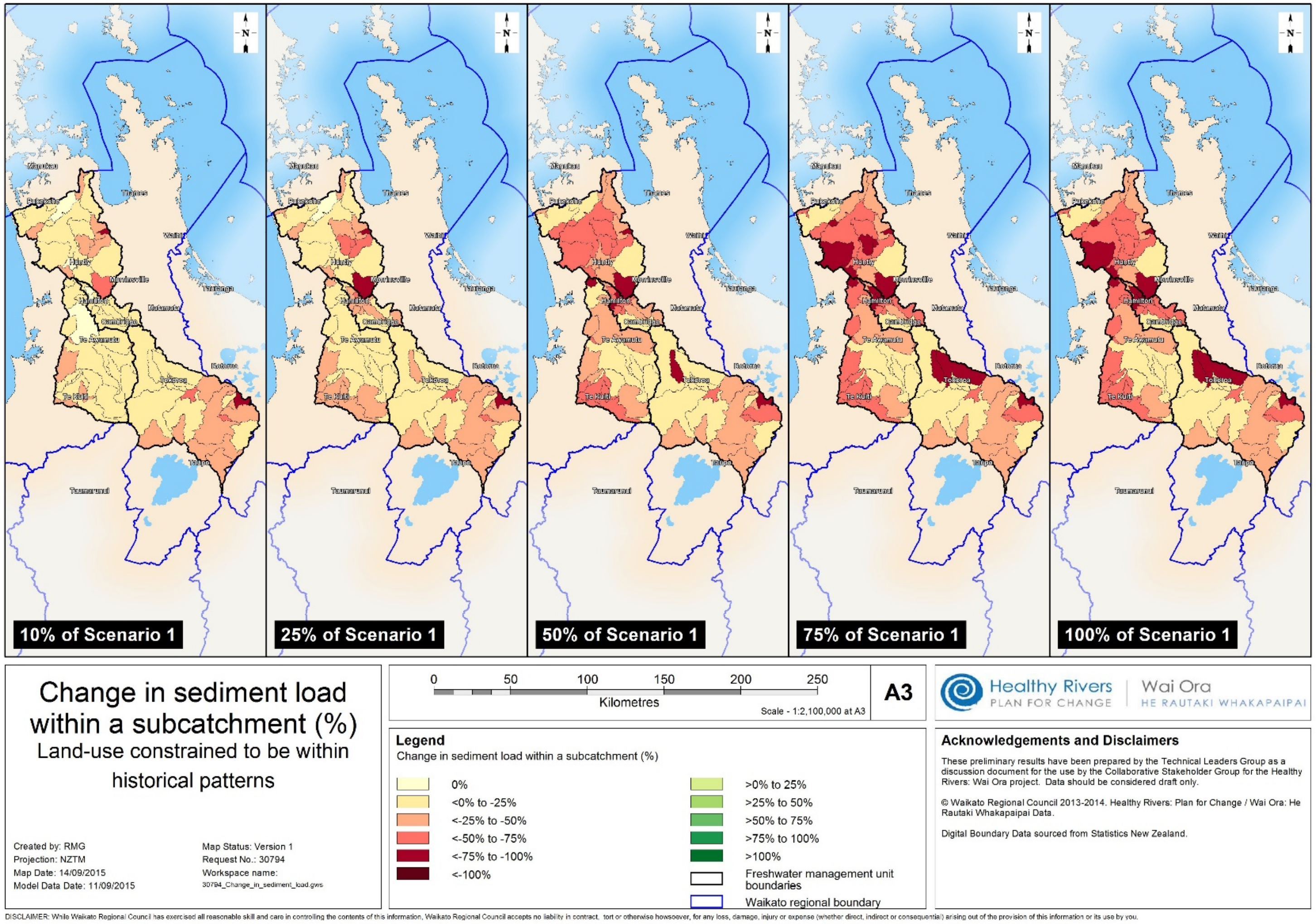

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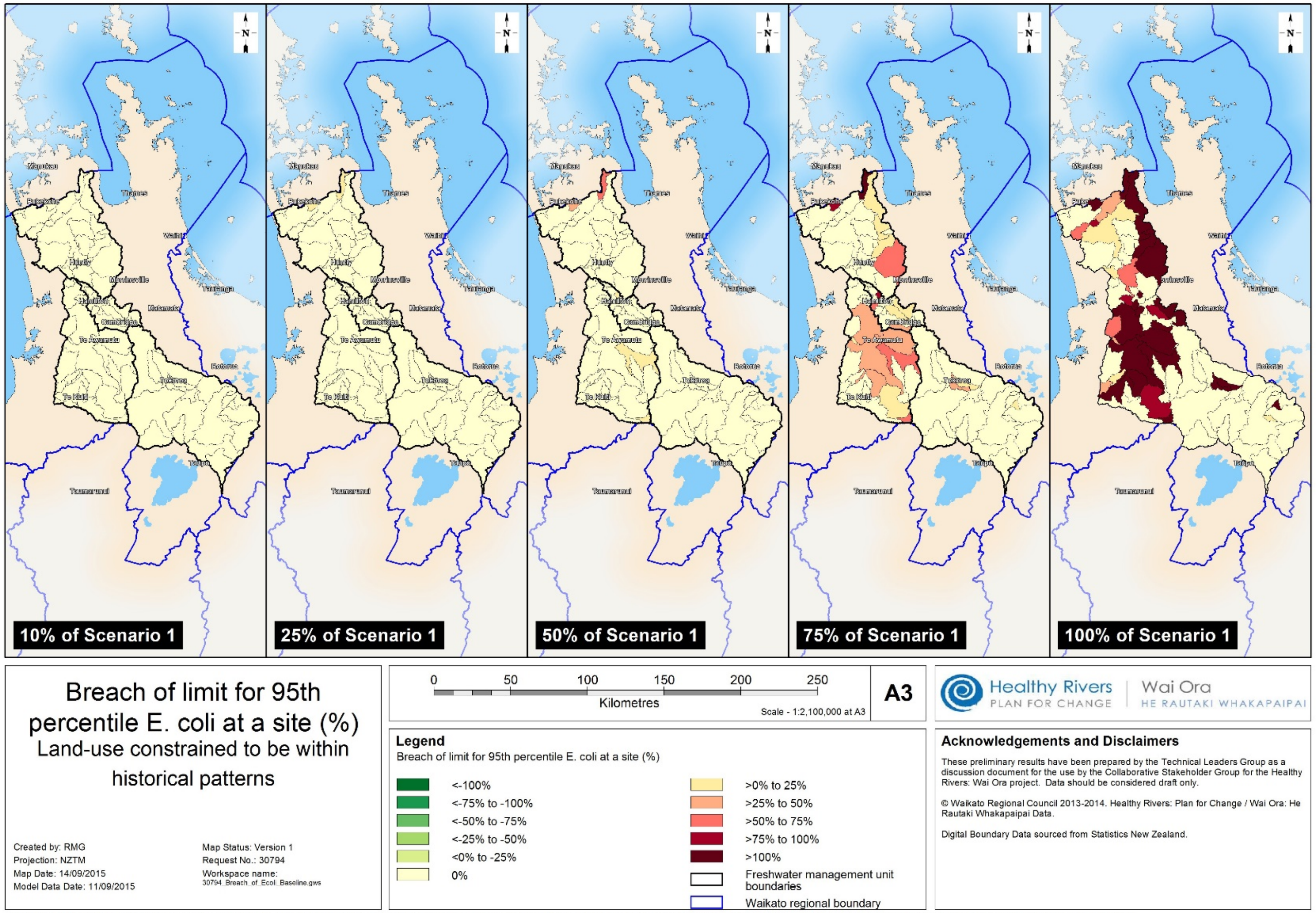
Figure 13. Breach of simulated 95th percentile *E. coli* limits in each sub-catchment, for constrained land-use change.



Breach of limit for 95th percentile E. coli at a site (%)
Land-use constrained to be within historical patterns

Created by: RMG
Projection: NZTM
Map Date: 14/09/2015
Model Data Date: 11/09/2015

Map Status: Version 1
Request No.: 30794
Workspace name: 30794_Breach_of_Ecoli_Baseline.gws

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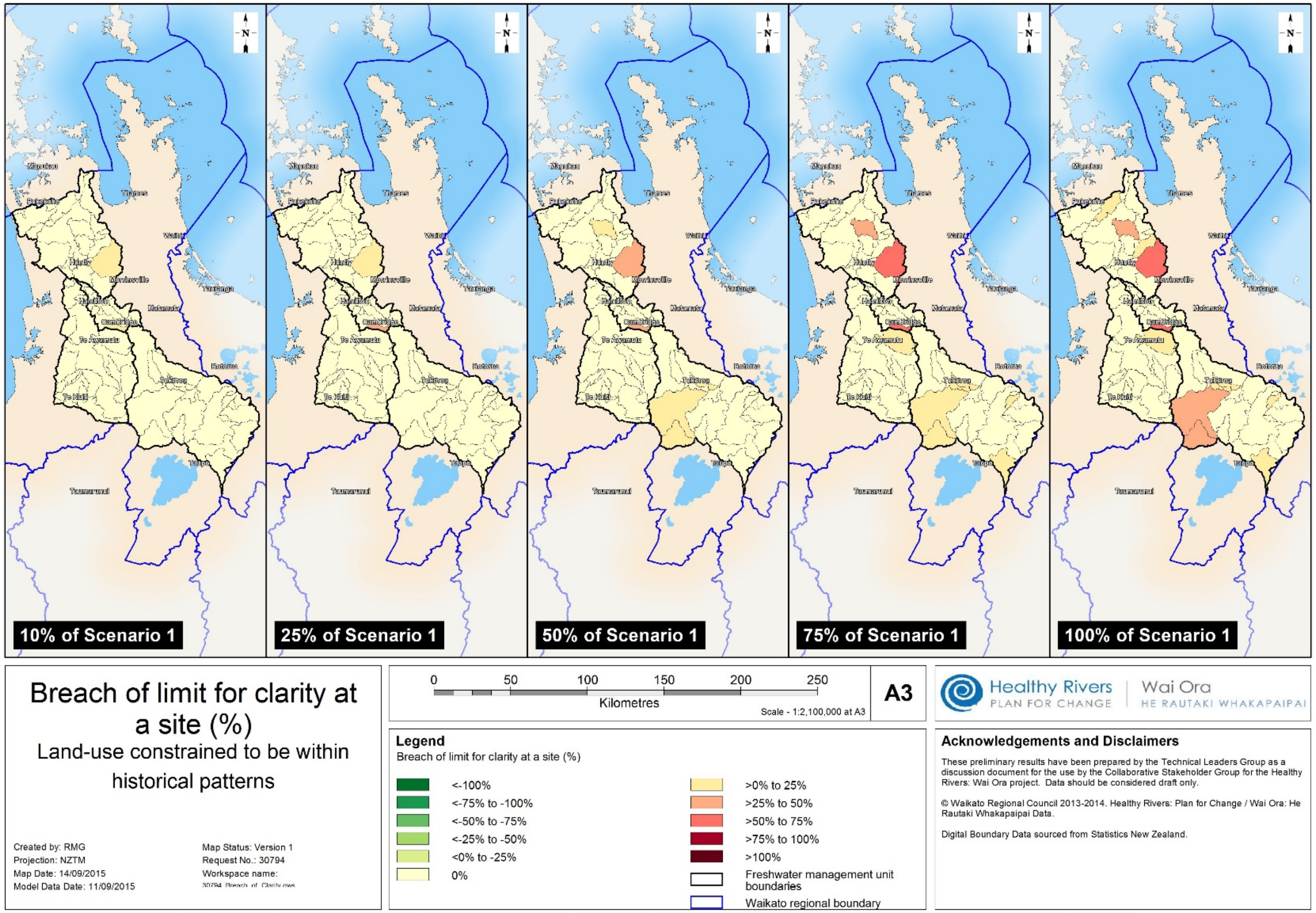
Figure 14. Breach of simulated clarity limits in each sub-catchment, for constrained land-use change.



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Digital Boundary Data sourced from Statistics New Zealand.

4. Conclusions

The Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai (HRWO) project will establish targets and limits for nutrients (nitrogen and phosphorus), sediment, and *E. coli* in water bodies across the Waikato and Waipa catchments. As part of the process of establishing targets and limits, the Collaborative Stakeholder Group (CSG) has asked for a technical assessment of partial movements from the current state towards the most-aspirational of the initial water-quality scenarios that they developed (Scenario 1). (Scenario 1 involves an improvement in water quality everywhere in the Waikato and Waipa catchments, even if it is already meeting minimum acceptable state). These partial movements constitute 10, 25, 50, 75, and 100% steps from the current state towards Scenario 1. The CSG might choose to consider these steps towards Scenario 1 as movements along a timeline of change.

An economic model—considering the farm-, catchment-, regional-, and national-level economic implications of water-quality limits—is utilised to investigate and predict these changes. This model represents a key contribution of the Technical Leaders Group (TLG) to the Healthy Rivers/Wai Ora process, given that it integrates diverse information generated from a broad array of work streams initiated and managed by this committee. This model is used to evaluate these steps towards Scenario 1 under a variety of cases: (1) land-use constrained to lie within those patterns observed historically; (2) land-use fixed at its current activity for 10% and 25% movements towards Scenario 1, and land-use change unconstrained for all other steps; and (3) land-use constrained to lie within those patterns observed historically, but with Total Nitrogen (TN) only required to stay at or beneath its current level.

A number of key findings are evident in model output:

1. The costs of 10% and 25% movements towards Scenario 1 are 3% and 7%, respectively, when land-use change is constrained to lie within those patterns observed historically.
2. Catchment-level costs increase sharply for simulated steps towards Scenario 1 that are above 25% with constrained land use. Indeed, the cost of a 50% step is more than three times that level observed for a 25% step (i.e. the annualised cost is $229m, compared with $68m).

3. Most costs experienced for the 10% and 25% steps fall on the dairy sector. Indeed, around two-thirds of the direct costs imposed at the 25% step fall directly on the dairy industry.
4. The 10, 25, and 50% steps towards Scenario 1 lead to a reduction in value added of $101m, $164m, and $221m in the greater Waikato region, respectively, and lead to the loss of around 1,198; 1,954; and 2,389 jobs, as well.
5. Nationally, the 10, 25, and 50% steps towards Scenario 1 are predicted to yield a reduction in value added of $212m, $339m, and $438m, respectively, and lead to the loss of around 2,276; 3,742; and 4,684 jobs.
6. The main industries that are detrimentally affected by water-quality improvement are the dairy; sheep, beef, and grain; and horticultural industries. The 25% and 50% steps towards Scenario 1 lead to a reduction in value added in the dairy industry of $101m and $127m in the Waikato region. The 25% and 50% steps towards Scenario 1 lead to a reduction in value added in the sheep, beef, and grain industries of $5m and $17m in the Waikato region, respectively. The 25% and 50% steps towards Scenario 1 lead to a reduction in value added in the horticultural industry of $3m and $10m in the Waikato region, respectively.
7. These negative impacts experienced within agricultural sectors flow onto the processing, utility, retail, and transport sectors. For example, the dairy-processing industry in the Waikato region loses between $31–$46m across steps of 10–50%, while around 200 jobs are lost in the construction and retail sectors as a result of the changes observed at the 50% step.
8. The 10% and 25% steps improve an index of median water-quality improvement by 14% and 23%, respectively, relative to the current state. The 50, 75, and 100% steps improve this index by 33, 42, and 43%, respectively, but impose significant catchment-level costs in doing so.
9. The mitigation packages that constitute the 10% and 25% steps contain a broad range of strategies. There is consistent upgrading of 2-pond systems and additional use of stream fencing, riparian buffers, afforestation, erosion-control practices on horticultural land, improved phosphorus management, and edge-of-field strategies.
10. There is a step-change in the necessary level of adoption for mitigation practices, as the steps move above 25% in progress towards Scenario 1. In particular, this is

observable in the targeted use of farm plans and broad-scale adoption of edge-of-field strategies.

11. Unconstrained land-use change allows a reduction in abatement cost, but requires substantial transformation of land use (around 50% of the catchment) in order to achieve these reductions.
12. Not defining limits for TN across the catchment (apart from maintenance of current state) has little effect on mitigation cost. A major reduction in TN occurs anyway to cost-effectively meet the simulated set of limits for the other contaminants, regardless of whether N itself is subject to limits or not. This arises from the fact that the most cost-effective strategies for phosphorus abatement (e.g. de-intensification, point-source improvement, and edge-of-field strategies) have dual benefit for reducing both nitrogen and phosphorus losses.

Overall, this economic analysis emphasises that changes in land management and land use are required to achieve the water-quality objectives set out in the updated set of scenarios developed by the CSG. These changes are likely to impose economic costs that vary spatially across the Freshwater Management Units defined within the HRWO process and the greater Waikato region itself.

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